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ABSTRACT

A hedonic model featuring quality-quantity tradeoffs reveals a number of surprising market behaviors that can result from price regulations that are imposed on competitive markets for products that have adjustable non-price attributes. Quality need not clear a competitive market in the same way that prices do, because quality can reduce the willingness to pay for quantity. Producers can benefit from price ceilings, at the expense of consumers. Price ceilings can result in quality-degradation "death spirals" that would not occur under quality regulation or excise taxation. The features of tastes and technology that lead to such outcomes are summarized with pairwise comparisons of (not necessarily constant) elasticities.

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Although not always highly visible outside of Communist countries, price regulations apply to a large fraction of economic transactions, even in the United States. There are, of course, controls on apartment rents and taxi fares in major cities, and minimum wages for low-skill workers. A number of states regulate interest rates on loans with usury laws and the federal government regulates interest and insurance rates with redlining prohibitions and antidiscrimination rules. Outside the state of Nevada, the price of sex is legislated to be zero. Basic telephone and cable TV rates are regulated. Price controls are the norm in the health sector, which by itself is already a sixth of the U.S. economy. Much modern research on business cycles features "sticky" prices, and the technology sector includes several markets with natural constraints on monetary prices: these are not exactly regulated prices but potentially share many of their economic characteristics.[1]

One view is that price regulations are, in the neighborhood of the unregulated price, more redistributive than they are socially costly even though they reduce the quantity traded.[2] For example, a price ceiling is supposed to create a benefit for buyers that almost offsets the loss it imposes on sellers. A number of studies have qualified these incidence and efficiency presumptions, noting that in addition to reducing supply, price ceilings may harm consumers by allocating the good to low-value customers (Barzel 1997, Glaeser and Luttmer 2003) or wasting consumer resources through queueing and search costs (Bulow and Klemperer 2012, Deacon and Sonstelie 1985). But product-quality changes, which have been widely documented and explicitly considered in a few of the previous models of price regulation, are another concern. Using a more general model of the technologically possible quality-quantity tradeoffs, our paper shows how a price ceiling imposed on a competitive market may increase the quantity traded, benefit producers at the expense of consumers, and have worse than first-order effects on efficiency – solely because the regulation affects non-price product attributes. We also concisely characterize the features of tastes and technology that lead to such outcomes.

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[1] See Lanier (2014). The degree of price stickiness can also be affected by regulation. For instance, item-pricing laws increase menu costs of changing prices, and result in less frequent price adjustments (Levy, et al. 1997). Unregulated industries with sticky prices may also have different cost structures than industries with regulated prices (Telser 2009).

[2] See, for example, Lee and Saez (2012).

Practically all goods and services have non-price dimensions (hereafter, "quality"), with sellers often spending considerable amounts as they attempt to make their product more attractive to buyers.[3] Non-price product attributes provide markets considerable scope for complying with a price ceiling without necessarily trading less quantity. Take apartments, for which it is sometimes said that the purchase price of land and structure equals the expected present value of the rental income to be received from tenants. In fact, about half of the revenues obtained from tenants is spent on short-run variable inputs rather than financing the structure's purchase or construction. Figure 1 shows the claims on national tenant-occupied housing output for 2006, as reported by Mayerhauser and Reinsdorf (2007). Almost half of housing output went to intermediate goods and services (e.g., banking, realtor and advertising activities) and depreciation (a proxy for normal repairs and maintenance). Another five percent went to labor (largely management), and about three percent went to compensate landlords for holding vacant units. Landlords could adjust any of these items in order to reduce the ratio of costs to revenue.[4]

Price ceilings have, in many real-world instances, increased quantity by reducing quality. One is the case of doctor appointments, where ceilings on the price per visit have sometimes resulted in patients' visiting the doctor more frequently for the same health condition. As Frech (2001, p. 338) puts it, Japanese patients "are often told to come back for return visits. And, even injections of drugs were often split in half to make two visits necessary." Cuba, among other places, has ceilings on the retail prices of eggs and other grocery items. Even though the grocery-price ceilings are far below what the retail prices would be, the grocery quantities sold are not. Instead, groceries there are sold in large

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[3] The quality dimensions include the time, place, or pleasantness of delivery. It could be the durability or reliability of the product, or the number of advertisements attached to it. Or the amount of customers' time that is required to acquire, finish, maintain, or consume the good. Or the size of the package.

[4] Also note that costs can, in effect, be negative. This was typically the case in the market for broadcast radio programming, where listeners paid no money but tolerated advertisements, which allowed broadcasters to cover their costs. The zero price for broadcast radio programming was set by technology rather than regulator or statute, but the example illustrates how an industry can function and competition occur without sellers' covering their costs exclusively from customer revenues.

containers and without refrigeration and other retail amenities.[5] Another example is the case of rent control of pre-war premises in Hong Kong, which appears to have increased the number of leases and perhaps even the number of square feet under lease as tenants engaged in partial subletting and landlords rented to "rooftop squatters."[6] Elsewhere, rent control appears to increase the fraction of apartments that are under lease (Block and Olsen 1981, pp. 108f, Gaumer and West 2015).

The quality-quantity tradeoff may be the source of these results. Holding expenditure constant, a price ceiling prohibits low quantities. Take retail grocery sales. Absent regulations, suppliers spend resources to preserve, cull, and promptly deliver their produce inventories so that the consumer receives fresh items. With a price ceiling set on, say, a per-ounce basis, suppliers cut down on their quality-enhancing expenditures and thereby reduce the share of groceries obtained by the consumer that is edible. Consumers with a price-inelastic demand for edible groceries purchase more total groceries because the survival rate of purchased groceries is reduced by the price ceiling. A variety of goods from apartments to light bulbs to doctor appointments have this feature that the unregulated market serves customers with less, but more expensive, quantity because that quantity is efficiently managed to provide the maximum value for the customer's dollar. Our model does not assume that controlled goods necessarily have such ease of substitution between quality and quantity, but these examples begin to show why the textbook predictions may not be reliable.

Even if a price ceiling does not increase the quantity sold, changes in non-price product attributes mean that the impacts of a ceiling on quantity and the surplus of buyers and sellers have little to do with the supply and demand for the controlled good by comparison to not having/producing the good at all. On the demand side, it is not the same when price falls by regulation as when it changes due to a reduction in the marginal

[5] Take eggs. Expressed as a ratio to the price received by producers in the U.S. market (there is no reliable data for the Cuban producer prices because the Cuban government has vertically integrated the production chain), U.S. retail egg prices are about 3 (U.S. Department of Agriculture 2016) whereas the Cuban retail price is controlled at about 4/3 (Loose 2016). Controlled Cuban eggs are sold in trays of 30 without lids or refrigeration (Mulligan 2016) while Cuban egg consumption per capita is at the world average and above that in comparable countries such as the Dominican Republic (The Poultry Site 2014).

[6] Cheung (2016) interprets these practices as choices to reduce rent dissipation, but they are also consistent with quality-quantity tradeoffs of the sort modeled in this paper.

costs of producing the services delivered by the controlled good. On the supply side, it is not the same when price falls by regulation as when it falls due to a reduction in the buyers' marginal willingness to pay for the services delivered by the controlled good. Even when the curves are properly adjusted to reflect changes in non-price attributes, the usual supply and demand diagram is not necessarily suitable for welfare analysis.

To the extent that supply slopes up, producers tend to benefit, relative to the unregulated allocation, from the increase in quantity and lose from the reduction in quality. Indeed, we find a simple supply-elasticity condition that indicates whether a price ceiling net redistributes from consumers to producers, or vice versa.

For conciseness, the scope of price regulations considered here is limited in three ways. First, the rest of this paper refers to ceilings, but not floors.[7] Our framework applies to price floors too, but ignoring them removes numerous provisos, inversions, etc., from the discussion. Also, the contrast between our results and previous ones are less subtle with ceilings than floors. Second, we do not consider price regulations that also specify the amount supplied.[8] Third, this paper features regulation-induced changes in non-price attributes that, holding price and expenditure constant, primarily affect the services consumers receive from the controlled good, rather than affecting the resources that the consumer has available for consuming other goods. The featured case encompasses the examples cited above: the price regulation is misspecified in the sense that it normalizes expenditure with a quantity (say, ounces of produce received from a retailer) that is different from what consumers ultimately value from the controlled good (edible ounces of produce). In the latter model, not treated in this paper, the price regulation is misspecified in that some of the expenditure on the controlled good occurs downstream of the price regulation, so that compliance is achieved by moving production downstream.

In formulating a competitive hedonic model with a variable quantity but a lack of heterogeneity among producers and consumers, our goal is ease of exposition. As with

[7] We also abstract from the case in which price ceilings become floors through regulatory capture.
[8] For example, supply could be conscripted, in which case yet additional factors are necessary to make predictions about the equilibrium quantity (Mulligan and Shleifer 2005, Mulligan 2015). Or the price regulation could also specify a rationing mechanism that itself restricts quantities, such as limiting how many items each household can buy (Taylor, Tsui and Zhu 2003). These are different than the competitive environment described here, but they are rarely described by the textbook analysis, either.

the textbook analysis of price ceilings and other public policies, we view the competitive case as a helpful starting point that focuses on tastes and technology, which by themselves have interesting and subtle features. Instead, the standard hedonic-model framework with unit demand is extended to allow for variable quantity in order to highlight quality-quantity tradeoffs that occur in the marketplace. Having a homogenous group of consumers (producers) allows us to show that quality adjustments are distinct in principle from the question of who consumes (produces) in the regulated market, respectively. Market power and heterogeneity can be added later (our Appendix I looks at some producer heterogeneity), and we presume that doing so will only enrich the already surprising range of market outcomes that come from quality adjustments by themselves.

Section I of the paper relates our findings to the previous literature. Section II introduces our model of tastes, technology, and market structure in a single industry, which is the standard competitive model except that quantity and quality are combined in a production function to produce the services desired by the industry's customers. Section III derives the effects of quality and price regulations on equilibrium quantity, quality, and social welfare. Section IV shows why producers may benefit from price ceilings. Section V concludes.

I. Previous studies of the effects of price regulation on product quality

Following Cheung (1974) and Leffler (1982), we assume that, although a price regulation prohibits competition on price, other forms of competition among buyers are not necessarily prohibited.[9] A supplier has an incentive to reduce quality in response to a price ceiling because doing so allows him to be compliant with the regulation without necessarily taking a loss (or forgoing a profit) on each unit sold.

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[9] See also Telser (1960) who explains self-imposed pricing restrictions on the basis of non-price competition.

Early contributions to the theory of consumer behavior with endogenous quality choice were made by Houthakker (1952) and Theil (1952). Becker (1965) and Lancaster (1966) extended the idea by treating quality and quantity as substitutable inputs in household production, with one of the most well-known applications being the tradeoffs between child quality and quantity (Becker and Lewis (1973)).[10] Rosen (1974) further extended the analysis to examine the properties of market equilibrium in a perfectly competitive environment, emphasizing the case in which consumers demand at most one unit. We introduce price control into that framework, but have consumers choosing quantity as well as quality.[11]

When good substitutes are available, a binding price control will simply induce a substitution away from the controlled good. A well-known example was the Regulation Q, under which the Federal Reserve fixed maximum interest rates that member banks could pay on time deposits, had stimulated the development of the Euro-dollar market (Friedman (1970) and Tobin (1970)). Many studies before ours, however, have also noted that regulated or rigid prices can result in less quality as buyers compete by accepting less of the non-price attributes. Economist and experienced price regulator John Kenneth Galbraith (1980) explained why regulators have difficulty preventing it.[12] Assar Lindbeck (1971, p. 39) noted the "deterioration of the housing stock" that results from rent control, adding that "next to bombing, rent control seems in many cases to be the most efficient technique so far known for destroying cities."[13] In discussing price controls during the Nixon administration, Barzel (1997, p. 20) noted that "[f]or many commodities the price controls caused inconveniences: fewer sales were made on credit, a smaller variety of goods was available, and free delivery was less frequent." Caps on physicians' fees are said to result in shorter appointments and longer wait times (Frech

[10] See also the discussion in Dreze and Hagen (1978) and Dixit (1979).

[11] As an alternative to the hedonic model, which has been widely used to study housing and labor markets in public economics and natural resource economics, random utility models have been applied in industrial organization and marketing to examine differentiated product markets where market power and strategic interaction are major concerns (see Anderson, de Palma, and Thisse (1992) for an excellent review).

[12] He cites the famous example of candy-bar price controls during World War II, to which manufacturers responded by putting less candy in each bar. Regulators hoped that they could prevent this reaction by setting the price ceiling based on the weight shown on the package, but failed to anticipate that, prior to controls, each candy package actually contained more weight than indicated, so that weight per package could be reduced while complying with the regulation.

[13] See Block and Olsen (1981) and Moon and Stotsky (1993) for evidence on this point.

2001). Numerous scholars, including Welch (1974), Hall (1982), Holzer, Katz and Krueger (1991), and Ippolito (2003) have noted that minimum wage laws may affect the non-pecuniary attributes of jobs. Frech and Samprone (1980) find that price regulation in the insurance industry affects the supply of non-price attributes. Boudreaux and Ekelund (1992) and Hazlett and Spitzer (1997) document that deregulating cable rates led to price increases driven by quality upgrades in the package (measured by the number of channels, program costs, etc.), whereas reregulation was accompanied by a dramatic drop in viewer ratings, which suggests a loss of quality. Gresham's Law says that currency-price regulations degrade the quality of money (Rolnick and Weber 1986).

It is also noted that queues can result from price ceilings, and take away from the customer experience (Taylor, Tsui and Zhu 2003, McCloskey 1985). But few of these, even those attempting to document the welfare costs of non-price rationing (e.g., Besley, Hall, and Preston (1999), Deacon and Sonstelie (1985), Hassin and Haviv (2003)), note that the supply of quantity shifts down, or that the willingness to pay for quantity may increase as buyers compete to accept less quality.[14] The supply effects have been noted in articles on "pure quality competition" (Abbott 1953, Gal-Or 1983) and in studies of specific industries in which competition occurs primarily in terms of quality (Steiner 1952, Koelln and Rush 1993), but our purpose is to provide a model that can represent a variety of non-price attributes and connect the impact of price regulations to properties of tastes and technology.[15]

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[14] Regarding retail gasoline price controls, Barzel's (1997, p. 21) did conclude that supply shifts down, noting that "[d]uring the period of price controls, market participants were able to alter the levels of gasoline transaction attributes not controlled by the government," such as lowering octane levels, excluding additives, shortening station operating hours, and requiring cash payment in order to reduce costs. However, Barzel assumes that adjustments of non-price attributes necessarily reduce the consumer's quantity demanded at any given price, which is contrary to our produce/lightbulbs/doctor appointments examples, and dramatically affects the results. See also Hall (1982) and our discussion of the Jevons (1866) paradox.

[15] Murphy (1980) concludes that a price ceiling might increase quantity sold, but, without featuring the quantity-quality tradeoff, does not examine other consequences of it. Leffler's (1982) discussion of price ceilings does emphasize the tradeoff, and notes that quality can reduce the demand for quantity. Neither paper provides clear conditions for determining the sign of a price regulation's impact on quantity or on the position of the demand curve.

II. The efficient production of quantity and quality

We follow the quality-quantity literature and specify a continuously differentiable household production function $Y(n,q)$ that uses quantity n and quality q. Quantity and quality are themselves produced with factors Z and z. Raw items, before any quality enhancements, are produced with one Z factor unit for each unit quantity n. z is used to make the quality enhancements: if q is the quality level and n is the number of items, then $G(q)n$ units of z are needed.[16] $G \geq 0$ is not necessarily globally monotonic in q, but we take it to be unbounded for q large enough and strictly convex and increasing in the relevant range. The marginal costs of supplying Z and z are $S(Z)$ and $s(z)$, respectively, with $S > 0$, $s > 0$, $S' \geq 0$, and $s' \geq 0$. The total costs g of producing goods of quality q in quantity n are therefore:

$$g(n,q) \equiv \int_0^n S(Z)dZ + \int_0^{nG(q)} s(z)dz \tag{1}$$

The supply conditions for the factors affect our results only insofar as they determine the shape of g. It is therefore worth expressing our technology assumptions in terms of g and Y, as in Assumption A and Assumption B (subscripts denote partial derivatives).

<u>Assumption A</u> g_q, g_{nq} and Y_q are positive in the relevant range. g_{qq} is nonnegative.

$Y_q > 0$ is just a normalization so that "quality" refers to more services rather than less. The assumptions about g_q and g_{nq} can be traced back to our assumptions about factor supply (S, s, and G; see Appendix II). As noted by Becker and Lewis (1973), a distinctive feature of quality-quantity tradeoffs relative to other economic tradeoffs is that the marginal cost of quantity increases with quality, and vice versa. Our production structure (1) captures this with its positive cross derivative g_{nq}, as compared to traditional models

[16] Our results still hold if quantity is produced with both factors, as is quality, as long as the cost function $g(n,q)$ satisfies the assumptions A and B (see below). Our purpose here is to transparently allow for the possibility (but not require) that quantity and quality have different supply conditions.

of two-good industries in which the marginal cost of one good is independent of the quantity of the other.

Y and g include both unit demand and constant costs as limiting or special cases. Unit demand would be the result if household benefits are minimal at positive quantities different from $n = 1$. If the resource costs g were proportional to n, then the average and marginal costs of production would be constant at a given quality.[17]

Assumption B contains our restrictions on the effect of quantity on the various costs and productivities:

<u>Assumption B</u> g_n and n are positive. g_{nn} is nonnegative. The partial elasticity of g_q with respect to n is at least one. Y_n and Y_{nq} are positive.

The assumptions about g's partial derivatives can be traced back to our assumptions about factor supply (S, s, and G; see Appendix II). The restrictions on Y_n and Y_{nq} say that quantity is a household production input that is complementary with quality.

It is sometimes convenient to summarize the production function Y and cost function g with,

$$\sigma(n,q) \equiv \frac{Y_n(n,q)Y_q(n,q)}{Y_{nq}(n,q)Y(n,q)}\,, \qquad \theta(n,q) \equiv \frac{g_q(n,q)}{n g_{nq}(n,q) - g_q(n,q)} \tag{2}$$

$\sigma(n,q)$ is a combination of the elasticity of substitution between inputs at allocation (n,q) and the returns to scale of Y in the two inputs at that point. If Y exhibits constant returns, or is a Cobb-Douglas function with any returns to scale, then $\sigma(n,q)$ is just the elasticity of substitution at allocation (n,q). In the grocery example from our introduction, one might take n to be the number of ounces of produce that the customer obtains at retail, q as the fraction of those ounces that are edible, and $Y = nq$ as the number of edible ounces. In this case, σ is the same constant for all (n,q) and equal to

[17] As we show below, even multiplicative separability for g is unnecessarily restrictive.

one.[18] This paper shows how the intuition from the produce example can be applicable to production functions with a lot less substitution between quality and quantity.

We refer to $\theta(n,q) > 0$ as the "price elasticity of the supply of quality" because, by definition, its inverse is $zs'(z)/s(z)$, which is the inverse of the elasticity of z's marginal cost. θ turns out to be an indicator of whether a price ceiling stifles competition among buyers, or among sellers, and thereby indicates the incidence of the regulation.

Some of the relations between production Y and factor costs g are usefully summarized by the minimum cost $c(Y,q)$ of producing Y with quality q:[19]

$$c(Y,q) = \min_{n} g(n,q) \quad s.t. \; Y(n,q) = Y \tag{3}$$

If we let $n(Y,q)$ denote the quantity achieving the minimum (3) for a given quality amount q, the impact of q on quantity is therefore the sum of a scale and a substitution effect:

$$\frac{dn}{dq} = n_Y \frac{dY}{dq} + n_q \tag{4}$$

The substitution effect n_q must be negative because the marginal products of quality and quantity are both positive (Assumptions A and B, respectively). In other words, the substitution effect by itself – moving along an isoquant for Y in the $[n,q]$ plane – says that regulation might *increase quantity* by reducing quality, even if quality and quantity are not particularly good substitutes in the production function in the sense of having an elasticity of substitution between zero and one. The scale effect is a movement from one isoquant to another.

To assess the direction and magnitude of the scale effect, it helps to concisely describe the efficient amount of services of the controlled good corresponding to any

[18] Raymon's (1983) model is a special case of $\sigma = 1$: it assumes that (a) $Y = nq$ and (b) the industry has perfectly elastic factor supplies. That paper does not report comparative statics for quantities.

[19] For q small enough relative to Y, there may not be any quantity that satisfies $Y = Y(n,q)$. However, that possibility is not relevant for an unregulated equilibrium (Y,q) pair (defined below).

quality level q. We assume that all households have the same preferences, which are quasilinear in all other goods:

$$\max_{Y} u(Y) - [I - c(Y, q)] \tag{5}$$

where I is the consumer's income that is used to finance Y and other goods.[20] We restrict the preference function u so that:

Assumption C u is continuously differentiable with $u'(Y) > 0$ and $u''(Y) < 0$ for all $Y > 0$. $u'(Y)$ is large enough near $Y = 0$ that a nonnegative amount of Y is efficient. Holding quality constant, the marginal willingness to pay for quantity is decreasing the quantity.

With Assumption C, the average and marginal value of consuming Y are different, although we do not rule out the possibility that the two values are close, as they would be as the u function becomes approximately linear in Y. In this sense, our preference setup is more general than some of the previous studies of quality that assume that any one consumer obtains the same marginal and average value from a purchase of a given quality because he is limited to purchase only one unit.[21] As we show below, cases with significant differences between marginal and average value have some of the opposite results.[22]

It is helpful to summarize u with:

[20] See also Spence (1975), Dixit (1979), and many others writing on product quality without income effects. Without income effects, our model (5) of the efficient amount of Y does not have to specify the division of surplus (the bracketed term) between producers and consumers.
[21] Bulow and Klemperer's (2012) paper examines the one-unit case, which they suggest to be applicable to "rental housing, health care, and minimum wages." Although we agree that it is uncommon for one family to have multiple rental houses or one worker to have more than one job, sometimes it is of interest to model the duration of time that a rented house is occupied or a job is held, and to do so without assuming that marginal and average values are the same.
[22] To be clear, we disagree with Spence's (1975, p. 417) assertion that it is "inessential" to assume that "each consumer buys only one unit of the good," even if values are heterogeneous across consumers. His assumption that average and marginal are the same at the consumer level is the source of the differences between his competitive results (his footnote 4) and ours.

$$\eta(Y) \equiv -\frac{u'(Y)}{u''(Y)Y} \tag{6}$$

which, not surprisingly, turns out to be the (not necessarily constant) magnitude of the price elasticity of demand for *Y*. In order to refer to elasticities, we normalize *Y* so that it is positive in the relevant range. It follows from (2) and (6) that η and σ are both positive.

$g_{nq} > 0$ makes for a more likely failure of the second-order conditions for minimizing the resource cost of *Y* jointly with respect to *n* and *q* (Hirshleifer 1955, Theil 1952, Becker and Lewis 1973). For example, there might be more than one quantity-quality mix that achieves the minimum cost. Assumption D rules out this possibility and thereby highlights that the "market multiplier" results to be shown later are not indicating non-convexities at the household level:

Assumption D The social surplus $u(Y(n,q)) - g(n,q)$ is jointly concave in quantity and quality.

Appendix II traces Assumption D back to assumptions about factor supply and production. Assumption D implies that, in the neighborhood of the efficient allocation, the conditional cost function is convex in quality.

The unconstrained efficient allocation is described by maximizing (5) with respect to both *q* and *Y*. Although they are not featured in this paper, increases in the preference for *Y*, or multiplicative reductions in the cost function *g*, would increase the efficient quality or quantity or both, according to the shape of the expansion path shown in the [*n*,*q*] plane.

Definition UR Given consumers' outside income *I*, an unregulated equilibrium is a price-quality schedule *p*(*q*), a pair of factor input prices *W* and *w*, profits *a*, factor quantities *Z* and *z*, a quality level *q*, and a quantity *n*, such that:

(i) The price *p*(*q*) of a *q*-quality good covers the factor costs of producing it:

$$p(q) = W + wG(q) \tag{7}$$

(ii) Given the price schedule $p(q)$ and factor income a, the quantity n and quality q maximize utility:

$$\{n, q\} = \underset{n \geq 0, q}{\operatorname{argmax}} \left[u\big(Y(n, q)\big) + I + a - p(q)n \right] \tag{8}$$

(iii) Factor suppliers' profits a satisfy (9) and (1)

$$a = p(q)n - g(n, q) \tag{9}$$

(iv) and, given the factor prices, factor supplies equal factor demands,

$$W = S(n) = S(Z), \qquad w = s\big(nG(q)\big) = s(z) \tag{10}$$

In effect, our exposition of the hedonic model of the market features price-taking intermediaries who are free to assemble the factors of production and sell final goods of the corresponding quality. These intermediaries earn zero equilibrium profits; the surplus on the supply side goes to the owners of the factors of production. This allows us to emphasize a pecuniary externality that, without wealth effects, is of no consequence absent regulation. In particular, the slope $p'(q) = wG'(q)$ of the equilibrium price schedule reflects the incentives of suppliers to upgrade the quality of the goods that they sell and the incentive of consumers to economize the quality of the goods that they buy. Any consumer that accepts less quality pays a lower price per unit quantity at the rate $p'(q)$. This pattern is not the same at the aggregate level because changes in tastes or technology also affect the factor prices. This feature of an unregulated equilibrium is not at all new, or even that interesting, but we show below that the situation is far different when prices are regulated.

Given our assumptions A-D, and that we are considering a competitive market, it is unnecessary to always show explicit notation for the factor prices and the components of consumer income. Moreover, the price schedule $p(q)$ is also superfluous because, at the equilibrium, consumers demand only one quality level. The same unregulated equilibrium quality, quantity, and price per unit can therefore be described more compactly as equilibrating quality and quantity according to (11) and (12).

$$g_q(n, q) = u'\big(Y(n, q)\big)Y_q(n, q) \tag{11}$$

$$g_n(n,q) = p \ = u'\big(Y(n,q)\big)Y_n(n,q) \qquad (12)$$

Because (11) and (12) contain marginal social benefits and costs, they show more directly that (a) the unregulated equilibrium is efficient (see also Rosen (1974) and followers) and (b) the unregulated equilibrium quantity maximizes both $pn - g(n,q)$ and $u(Y(n,q)) - pn$. (11) and (12) also turn out to be good benchmarks for outcomes under regulation.

III. Regulated competitive equilibrium

This paper is about price regulations rather than quality regulations, but the latter are both of intrinsic interest (Rosen 1974) and highlight some of the economic effects of the former. Each of them add a constraint to (12):

Definition QR Given a quality ceiling $\bar{q}$, a quality-regulated equilibrium is a quantity n and a price p such that (i) n maximizes $u\big(Y(n,\bar{q})\big) - pn$ taking p and $\bar{q}$ as given, and (ii) n maximizes $pn - g(n,\bar{q})$ taking p and $\bar{q}$ as given.

Definition PR Given a price ceiling $\bar{p}$, a price-regulated equilibrium is a quantity n and a quality level q such that (i) n maximizes $u\big(Y(n,q)\big) - \bar{p}n$ taking $\bar{p}$ and q as given, and (ii) n maximizes $\bar{p}n - g(n,q)$ taking $\bar{p}$ and q as given.

Note that, for a given quality level $\bar{q}$, the price p refers to the revenue per unit quantity, and not revenue per unit output Y. In both cases, quantity is an equilibrium variable.

It may seem odd that price-regulated consumers take quality as given, but remember that sellers are not obligated to supply any particular quality level and therefore do not supply any quality level that has more than $\bar{p}$ of factor costs per unit quantity.[23] In other words, the price-regulated market has an endogenous ceiling – from

[23] As with Definition UR, QR equilibrium and PR equilibrium each have production occurring with the two factors Z and z and the price per unit quantity equal to the per-unit factor-rental costs

the market rather from regulators – on the quality that consumers can obtain. Definition PR goes further by making the consumers' constraint an equality – they must accept quality level q – rather than an inequality. In other words, we assume that the price ceiling is binding and build that assumption into the definition above.[24] Definition QR analogously assumes that quality regulations bind.

Both definitions yield a supply-side first-order condition that equates price to the marginal cost of quantity g_n and a demand-side condition that equates $Y_n u'$ to price. That is, the same two equations (12) are satisfied by both a quality-regulated equilibrium and a quantity-regulated one, with the price-regulated (quality-regulated) equilibrium adding the equation $p = \bar{p}$ ($q = \bar{q}$), respectively. Because the marginal cost of quantity is nondecreasing in quantity (Assumption B) and the marginal benefit of quantity is decreasing (Assumption C), Definition QR is just a supply and demand competitive equilibrium with the usual slope and stability properties. In particular, (i) price is a competitive equilibrium variable: it is not "set" by anyone in particular, (ii) a quality-regulated equilibrium is unique and (iii) a marginal change in the quality ceiling has a marginal impact on price and (at most) a marginal impact on quantity.

We define a price-regulated equilibrium in a symmetric fashion. In particular, given a regulated price, consumers and producers choose quantity as a quality-taker. However, as we shall see below, quality does not clear the market in the same way as price does even under the standard assumptions for tastes and technology, because for any given price a lower quality can increase quantity demanded which may bid up factor prices.

III.A. A quality ceiling increases the supply of quantity, and may also increase the willingness to pay

Under quality regulation, price clears the market in the usual way. Proposition QR gives the comparative statics:

(UR item (i)). However, as discussed above, we subsumed all of the factor-market transactions into the cost function notation $g(n,q)$.

[24] It is widely recognized that a price ceiling set at $\bar{p}$ could be lax enough that it does not bind in the sense that the unregulated market price would be $p < \bar{p}$. We have nothing to add to this point, and therefore focus on regulations that are binding.

Proposition QR The quality-regulated equilibrium is unique. Lowering the quality ceiling can increase the equilibrium quantity, and must do so if the equilibrium σ equals or exceeds η.[25] The equilibrium comparative statics with respect to $\bar{q}$ are:

$$\frac{dn}{d\bar{q}} = -\frac{D_q}{D_n} \tag{13}$$

$$\frac{dp}{d\bar{q}} = (1-\beta)g_{nq} \tag{14}$$

where

$$D(n,q) \equiv u'\big(Y(n,q)\big)Y_n(n,q) - g_n(n,q) \tag{15}$$

$$\beta(n,q) \equiv \frac{D_q(n,q)}{D_n(n,q)}\frac{g_{nn}(n,q)}{g_{nq}(n,q)} \tag{16}$$

D(*n*,*q*) denotes the gap between the willingness to pay and the marginal cost of quantity, which has an equilibrium value of zero.[26] $D_n < 0$ is therefore the difference between the willingness-to-pay function's slope and the marginal cost curve's slope. D_q, and therefore the direction of the quantity impact, is ambiguous. A quality ceiling reduces the marginal cost of producing quantity, which would increase quantity if the willingness to pay – the right-hand side of (12) – remained constant at each quantity.

More surprisingly, a quality ceiling can also increase the willingness to pay. To see this, it helps to look at the willingness to pay drawn in the [*n*,*p*] plane, as in Figure 2, for fixed quality levels. Assumption C requires that the willingness-to-pay curve slopes down, but none of the assumptions requires that quality increase the willingness to pay at all points, or any points, on the curve. As an example consistent with light bulbs and grocery-store produce, consider $Y = nq$, with a *Y*-demand function u' that has a finite negative slope everywhere. At the demand choke point $n = Y = 0$, the willingness to pay is $u'(0)\bar{q}$, which necessarily increases with the quality ceiling $\bar{q}$ because the consumer

[25] Recall that σ and η are functions of (*n*,*q*).
[26] *D* is related to Cheung's (1974) concept of non-exclusive income.

gets more output from a high-quality good than a low-quality one. But the high-quality good also moves the consumer further down his *Y*-demand curve, which reduces his marginal willingness to pay for *Y*. As a result, in the neighborhood of the choke point, the high-quality demand curve is above and steeper than the low-quality one.

More generally, the direction of the effect of quality on the willingness to pay at any point on the quantity-demand curve is the sign of $(\eta - \sigma)$ at the same point. Wherever the difference is negative, consumers are more willing at the margin to substitute quantity, rather than other goods, for quality: a tighter quality ceiling increases their willingness to pay at that point. When the difference is positive, a quality ceiling reduces the willingness to pay.[27] If *Y* demand also has a satiation point, which we assumed for the purposes of drawing Figure 2, then willingness-to-pay curves corresponding to different qualities must cross – that is have points with $\eta > \sigma$ as well as points with $\eta < \sigma$ – because it takes more quantity to reach satiation with low quality than with high. It is possible that the curves cross more than once. Conversely, the only way to have the high-quality curve always above (below) the low-quality curve is for Y-demand to have no satiation (choke) point, respectively.[28] A constant-elasticity demand curve is an example of one without a choke point and is consistent with no positive impact of quality on the willingness to pay for quantity at any point on the curve.[29]

Because the existence and location of the crossing point depends only on the properties of the preference functions *Y* and *u*, that point could be on either side of the unregulated equilibrium point. Our Figure 2 shows the case where the crossing point is to the left of the unregulated equilibrium and a quality ceiling locally increases the

[27] The positive-difference case conforms with the Jevons (1866) paradox: increasing quality (say, the productivity of coal) increases the willingness to pay for each pound of coal because it sufficiently expands the use of coal-sourced energy.

[28] To be clear, we say that there is a choke point if (a) the willingness to pay for *Y* is finite at $Y = 0$ and (b) $Y(0,q) = 0$ for any quality in the relevant range. We say that there is a satiation point if (a) the willingness to pay for *Y* is zero for a finite amount of *Y* and (b) the satiation service level can be achieved with finite amounts of quantity and quality. Here we use satiation and choke points to help describe the global properties of the demand system, but note that a satiation point is of practical interest in those markets where the price ceiling is zero (i.e., buyers are prohibited from paying the sellers).

[29] Spence (1975), Frech and Samprone (1980), Ippolito (2003), and others use the area under the demand curve in the $[n,p]$ plane to measure the impact of quality on consumer welfare, but, if the demand curve has no choke point, there is also a constant of integration that must be considered. This caveat is most obvious in the case in which quality does not shift the demand curve, and therefore has no effect on the area under it, even though quality affects welfare.

willingness to pay by reducing quality. In other words, the consumer's demand for the final output is locally relatively inelastic and he reacts to a quality ceiling by purchasing a greater quantity in order to maintain something close to the unregulated output level.

A potentially large segment of the willingness-to-pay schedule can have $\sigma = \eta$, as would be the case if the elasticity of substitution σ were a constant for all (n,q) and a segment of the Y-demand curve had a constant elasticity of the same magnitude. We show this case in Figure 3A in order to focus on supply effects. Because quality and quantity interact in costs, a quality limit shifts the marginal cost schedule down by reducing quality. The willingness-to-pay schedule does not shift in the relevant range, and the equilibrium result is more quantity and a lower price.

It follows that, as long as supply is at least a small bit price sensitive, $\sigma \geq \eta$ is sufficient but not necessary for a quality reduction to increase the quantity purchased. An equilibrium quantity reduction would require that η be enough greater than σ that the scale effect of the regulation on quantity be in the right direction and of sufficient magnitude to offset the substitution effect. In other words, in order for the regulation to reduce the equilibrium quantity, quality changes must, in the neighborhood of the unregulated allocation, reduce the willingness-to-pay schedule more than they reduce the marginal cost schedule. Conversely, for any functions Y and g satisfying our assumptions A-D, there exists preferences u such that the equilibrium impact of a quality regulation is to increase the quantity sold and to increase the willingness to pay for quantity in the relevant range.[30] These surprising results are not solely a matter of the degree of substitution between quantity and quality.

As long as factor supplies are not perfectly elastic ($g_{nn}(n,q) \neq 0$), the equilibrium impact $-D_q/D_n$ of $\bar{q}$ on quantity n can be decomposed into a component that holds marginal cost constant – a shift of the marginal cost schedule $g_n(n,q)$ in the quantity dimension in the amount $-g_{nq}(n,q)/g_{nn}(n,q) < 0$ – and the movement along the schedule. $\beta(n,q)$, defined in (19), is the ratio of the equilibrium impact to the schedule's shift and has the same sign as its numerator. $\beta - 1$ has the same sign as the equilibrium price

[30] Specifically, as η approaches zero, the locus of equilibrium combinations of q and n is just an isoquant of Y, which must slope down in the $[n,q]$ plane.

impact. As we show in some detail below, β can exceed one and quality regulation can move price and quality in opposite directions.[31]

III.B. A price-regulated equilibrium may not be unique, or stable

It is frequently claimed that waiting or some other non-price attribute clears the market when price does not (Abbott 1953, Deacon and Sonstelie 1985, Raymon 1983), albeit somewhat less efficiently. This claim can be evaluated with our PR model by looking at the quantity demanded and supplied each as functions of quality, holding price constant. In order to maintain the analogy with markets that clear with prices, Figure 4 shows the inverse of quality on its vertical axis.[32] Assumptions A and B guarantee that the "supply" curve does not slope down and that it shifts down with p. Because Assumption C requires that the willingness-to-pay curve slopes down in the $[n,p]$ plane, $\bar{p}$ must shift Figure 4's demand curve to the left. If, contrary to the figure, that curve sloped down everywhere in the $[n,1/q]$ plane, then the PR equilibrium would have the qualitative features of the usual supply and demand equilibrium, e.g., that it would be unique and stable as in the prototype supply and demand picture with downward-sloping demand.

However, Figure 2 shows why the willingness to pay can fall with quality, and probably does over some range. In this case the "demand" curve would slope up in the $[n,1/q]$ plane. The sign of its slope at any point is the same as the sign of $1/(\sigma - \eta)$. At any point where supply and demand cross, the ratio of the supply slope to the demand slope is qualitatively summarized by β: the two are on the same side of one. In particular, an equilibrium has a positively-sloped demand curve that crosses supply from

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[31] Note that measuring the magnitude of the various derivatives with respect to any monotone transformation of quality, rather than quality itself, would not affect the magnitudes of β and σ/η.

[32] The supply curves in the Figures are implicitly defined by $\bar{p} = g_n\left(n, \frac{1}{y}\right)$ where y is measured on the vertical axis and n on the horizontal. The demand curves are $\bar{p} = u'\left(Y\left(n, \frac{1}{y}\right)\right) Y_n\left(n, \frac{1}{y}\right)$. Any monotone decreasing function would result in the same qualitative patterns because in effect, Figure 4 describes the qualitative properties of the level curves of marginal cost and marginal willingness to pay for quantity.

above if and only if $\beta > 1$. This possibility is a fundamental difference between prices and quality as allocators of quantity.[33]

Because supply and demand can both slope up, the supply and demand curves can cross multiple times, as in Figure 4. In contrast to a QR equilibrium, a PR equilibrium need not be unique or stable. At an unstable equilibrium ($\beta > 1$), a small deviation in the direction of less quality means that the quantity demanded exceeds quantity supplied, which only encourages buyers to accept less quality. A stable equilibrium ($\beta < 1$) either has demand sloping down or crossing supply from below. These two possibilities are shown as the upper right and lower left black circles, respectively, in Figure 4.

The curves shown Figure 4 are for a single value of $\bar{p}$. That value could be the unregulated equilibrium price, which is unique and stable.[34] In other words, part of the reason that the unregulated equilibrium and the QR equilibrium are each unique and stable is that price can adjust. With price held fixed, quality adjustments can be a particularly poor way of coordinating consumers and producers. Quality looks more like a price when $\beta(n,q) < 1$, as explained in Proposition PR.

<u>Proposition PR</u> A price-regulated equilibrium with $\beta(n,q) < 1$ is stable. The equilibrium comparative statics with respect to $\bar{p}$ are:

$$\frac{dn}{d\bar{p}} = \frac{D_q/(-D_n)}{g_{nq}} \frac{1}{1-\beta} \tag{17}$$

$$\frac{dq}{d\bar{p}} = \frac{1}{g_{nq}} \frac{1}{1-\beta} \tag{18}$$

Note that, with $\beta < 1$, PR equilibrium and QR equilibrium have the same comparative statics in the sense that the two ceilings have the same marginal effects as long as they are scaled according to (14). It follows from the two propositions that, with $\beta < 1$, $\sigma \geq \eta$ is sufficient but not necessary for a price ceiling to increase the equilibrium quantity.

[33] For other differences, see Telser (1987) and Weitzman (1974).
[34] This follows from Assumption D. See also Appendix II and Rosen (1974).

More surprising is that the magnitudes of the marginal price-ceiling impacts can be arbitrarily large, namely when β is close enough to one. This occurs with an equilibrium such as the lower left crossing in Figure 4. Tightening the price ceiling shifts the supply curve up, with the magnitude of the movement up the demand curve depending on the difference between their slopes. The slopes are especially close when β is close to one. In other words, $\beta \in (0,1)$ means that suppliers' quality-cutting attempts to comply with the ceiling are partly frustrated in the aggregate as the increased quantity demanded raises marginal cost by raising the price of factors used to produce quantity. Equilibrium compliance with a price ceiling thereby requires more of a quality reduction than it would if factor prices were constant. For this reason, we refer to β as the " market multiplier."[35]

Figure 5A graphs the locus of price-regulated equilibrium quality-price combinations, holding constant the taste and technology functions u, Y, g.[36] The locus slopes up if and only if $\beta < 1$. We draw one downward-sloping portion on the quality interval $q \in [q_2, q_1]$, where $\beta > 1$, although for some taste and technology functions there may not be any downward-sloping portion (there also could be multiple parts with $\beta > 1$). The companion Figure 5B shows the locus of equilibrium quantity, assuming that supply is neither perfectly elastic nor perfectly inelastic. It is, qualitatively, the horizontally mirrored image of Figure 5A wherever $\beta > 0$ and thereby in those cases closely resembles the demand curve drawn by Becker (1991, Figure 2). The point $(n_1, \bar{p}_1)$ in Figure 5B represents the same equilibrium as the point $(q_1, \bar{p}_1)$ in Figure 5A. The same relation holds for $(n_2, \bar{p}_2)$ and $(q_2, \bar{p}_2)$. Because the market multiplier does not have to be positive, especially for low ceilings, we show two upward-sloping parts in Figure 5B. One of them slopes up because $\beta > 1$ and the other because $\beta < 0$.[37]

Nothing is shown or assumed in Figures 5A and 5B about the price, quality, or quantity that would prevail without regulation. In theory, the multiplier formula (16)

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[35] There is a resemblance with Becker's (1991) and Becker and Murphy's (2003) competitive analysis of "social interactions." See also Figure 5B and Appendix II.

[36] It is a graph of $\bar{p} = M\big(Y(n,q)\big)Y_n(n,q)$, but only for combinations (n,q) that are a PR equilibrium for some $\bar{p}$.

[37] As in Becker's (1991) model, the nonmonotonic relationship between price and quantity shown in Figure 5B is therefore not the result of failures of the second-order conditions of competitive market participants.

could be evaluated at the unregulated quantity and quality. The result says little about unregulated comparative statics, but it would be informative about some of the consequences of imposing a price regulation on that market. Figure 5C illustrates with a zoomed-in version of Figure 5A for the case in which the market multiplier exceeds one at the unregulated allocation shown as *U*. A price ceiling introduced below, but close to, the unregulated price, the regulation would (a) induce a discrete quality reduction (from q_u to $q_r << q_u$), (b) harm consumers, (c) benefit producers, (d) cause a discrete loss in social surplus,[38] and, if the supply of quantity were at all responsive to prices, (e) increase expenditure and the quantity sold. To prove the second and third points, note that, absent regulation, a consumer chooses quality q_u and pays p_u per unit quantity, even though he could obtain q_r more cheaply (namely, at a discount of $(q_u - q_r)g_q/n$ per unit). In effect, a price ceiling close to p_u forces each consumer to accept quality q_r without receiving the discount that is available absent regulation.[39] Meanwhile, producers benefit from the price ceiling because they deliver less quality and get essentially the same price per unit, thereby getting more surplus from the first n_u units they produce and getting a nonnegative surplus on the remaining $(n_r - n_u)$ units.[40]

To prove the remaining points, note that small quality reductions are not enough to comply with a price ceiling, regardless of how close the ceiling is to the unregulated price p_u, because quality reductions by each supplier frustrate the compliance attempts by the others. Quality must fall at least to q_r. *R* is a regulated equilibrium for a price ceiling that is near the unregulated price, and therefore has essentially the same marginal cost of quantity as the unregulated equilibrium does. Because (i) the marginal cost schedule $g_n(n,q)$ is increasing in both arguments and (ii) $q_r < q_u$, expenditure and quantity at allocation *R* must exceed what they are at allocation *U* unless the supply of quantity is completely inelastic to price, in which case $n_r = n_u$. These results for quantity, expenditure, and the allocation of surplus are our first of several that are essentially opposite of the textbook analysis, where a price ceiling benefits consumers (and, if

[38] Note that the regulation induces a discrete movement along the conditional cost function in the quality dimension, away from the conditional-cost-minimizing quality.
[39] The algebraic proof uses the consumer's value function $v(q) \equiv \max_n u(Y(n,q)) - \bar{p}n$, which, given $\bar{p}$, is strictly increasing in the quality level q.
[40] Because $\beta < 1$ at the allocation *R*, further reductions in the ceiling may reduce producer surplus below what it is at *R*, and perhaps even below what it is at *U*.

supply is competitive, reduces quantity) as long as the ceiling is close enough to the unregulated price.

Consider Figure 5C again. A price ceiling of $\bar{p} \in (p_u, \bar{p}_2)$ introduced to the unregulated and efficient market U might have no effect, because the unregulated equilibrium price and marginal cost g_n are less than such a ceiling. However, for a regulated market with a ceiling at (or nearby and below) p_u, relaxing its ceiling to a level in the interval $(p_u, \bar{p}_2)$ may not result in the efficient allocation. An individual seller does not, given the factor prices prevailing at R, have an incentive to supply as much quality as q_u because he would need to charge more than $\bar{p}_2$, which would be in violation of the regulation. The problem is that quantity-quality substitution that resulted in the quality level q_r makes the marginal unit of quantity more expensive to produce than it is in the unregulated economy. In order to willingly supply the efficient quality, an individual seller must not only see the price regulation relaxed above p_u, but also anticipate that the other sellers will supply the efficient quality, rather than the quality level between q_2 and q_u that corresponds to the relaxed ceiling and is part of a stable regulated equilibrium. We leave a rigorous dynamic analysis for future research, and here just note that Figure 5C might have some of the foundations for a conclusion that the effects of price regulation depend not only on tastes and technologies, but also the market's prior regulatory history. With this possibility for the efficient allocation to be unstable absent price adjustments, our price-regulation analysis has some resemblance with (special cases of) insurance premium "death spiral" models in which a relatively efficient allocation can be supported as a competitive equilibrium, but that equilibrium is unstable because equilibrium pricing is inefficient (Feldman and Dowd 1991).[41]

[41] Although it is not the case for the situation shown in Figures 5A-5C, it is theoretically possible that no stable price-regulated equilibrium exists (any unregulated equilibrium is stable, and unique). However, in any application with a Y-demand curve that has a choke point with a finite negative slope, η approaches infinity as one moves along that demand curve toward the choke point, which means that $\beta < 1$ in that neighborhood. In other words, willingness-to-pay schedules consistent with Figures 5A-5C may be look like those drawn in Figure 2. See also the numerical example shown in Appendix II.

III.C. Welfare costs that are worse than first order

The social welfare losses from a quality regulation are second-order because consumer willingness to pay is smooth and the unregulated equilibrium has a quality level that minimizes total conditional costs $c(Y,q)$ (recall equation (3)). This resembles the textbook model where price regulations create second-order losses. However, if the unregulated allocation has $\beta > 1$, then it is unstable as a price-regulated equilibrium. A price ceiling below the unregulated price level, no matter how close, produces a discrete reduction in quality and therefore in social welfare. As shown above, consumers are discretely worse off and producers may be better off.

These welfare results are not only directionally different from the textbook analysis, they are of an entirely different character. Indeed, they are different from most tax analyses, where imposing a small tax on an otherwise efficient market creates only second-order welfare losses.[42] The reason is that, say, an excise tax creates a gross-of-tax price that is automatically indexed to marginal cost. In contrast, a price regulation is typically not indexed to marginal cost and thereby cannot prevent discrepancies between price and marginal cost that are arbitrarily large.[43]

Figure 6 illustrates the distinction, under the assumption that $g_{nn} > 0$, which means that the supply of quantity is less than perfectly elastic. The horizontal axis measures the amount by which the price ceiling $\bar{p}$ is set below the unregulated price p_u. Allocations to the left indicate ceilings that are close to the unregulated price while those to the right indicate more severe price ceilings. The vertical axis measures the impact of the ceiling on various outcomes. The green and red curves describe the impact when the market multiplier β is at least as large as one at the unregulated allocation. Regulated quantity n and expenditure $\bar{p}n$ (green curve) are each discretely higher than its unregulated

[42] Although rarely analyzed, tax rates that are indexed to market conditions could result in multiple equilibria and "multiplier" comparative statics. One such tax is the "Rising-Tide Tax System" (Burman, et al. 2006) that proposes to index the rate of taxation of high earnings to market outcomes for the high earners. The paper containing the proposal and analysis thereof fails to note that high tax rates might make skills more scarce, and thereby result in a feedback loop in which rising tax rates and falling skills quantities mutually reinforce each other (we owe this point to Kevin M. Murphy).

[43] This result resembles Hayek's (1945) exposition of the socially important role of market prices in coordinating human activity. See also Appendix II.

counterpart, although they tend to decline as the ceiling gets more severe.[44] Total surplus u, consumer surplus $(u + g - \bar{p}n)$, and quality q are each discretely less than its unregulated counterpart (see the red curve). They continue to decline with further increases in the ceiling. Compare the green and the red curves, which relate to multipliers of at least one, with the black and blue curves, respectively, which relate to multipliers less than one. In the latter case, each of the outcomes is close to its unregulated counterpart (i.e., the origin) as long as the price ceiling is close enough. Moreover, with $\beta < 1$, the marginal effect of the ceiling on total surplus is zero in the neighborhood of the unregulated allocation (see the gray curve).

A full analysis of efficient and robust redistribution is beyond the scope of this paper, but Figure 6 already suggests that such an analysis must account for the different character of the redistribution that occurs for $\beta < 1$ and $\beta > 1$. If the sign of $(\beta - 1)$ were unknown, consumers' expected loss from a price ceiling could well be negative even though a gain were far more likely than a loss, because the amount lost conditional on losing is of a different order of magnitude than the amount gained conditional on gaining.

Note that Barzel (1997), Glaeser and Luttmer (2003) and others have argued that price ceilings create first-order social losses due to the rationing mechanism used to resolve the "shortage." These allocative losses have been ruled out in our approach, which treats all consumers as identical and has no shortage (unless the shortage is interpreted as a non-price product attribute – see below). In other words, a large market multiplier is an additional reason why the losses from price regulation need not be second order. Moreover, unlike first order losses, the losses that occur in our model with $\beta > 1$ cannot be made arbitrarily close to zero with a judicious (but binding) level for the price ceiling.

III.D. Example: Quantity is in fixed supply

The special case with inelastically-supplied quantity is potentially applicable to rent control and other price regulations where supply is fixed in the short run, but it also highlights some of reasons why β could exceed one. Given n and $\bar{p}$, a price-regulated

[44] Although not shown in Figure 6, there may be a range where quantity increases at the margin with ceiling severity because the ceiling has not yet sufficiently increased the marginal cost of Y.

fixed-quantity equilibrium is a quality limit q that satisfies $\bar{p} = u'\big(Y(n,q)\big)Y_n(n,q)$. At the unregulated allocation, the market multiplier is:[45]

$$\beta(n,q) \to 1 + \left(\frac{\sigma(n,q)}{\eta(n,q)} - 1\right) \frac{n}{g_q(n,q) + q g_{qq}(n,q)} u'\big(Y(n,q)\big)Y_{nq}(n,q) \qquad (19)$$

It follows that, with inelastic supply, the multiplier at (n,q) exceeds one if and only if the elasticity σ of substitution in production exceeds the magnitude η of the price elasticity of Y-demand at that point.[46] Because, as shown in Section II, any continuous demand curve with a satiation point has points on it with $\eta < \sigma$, there must also be points with $\beta >$ 1.

When the supply of quantity is fixed at n, Figures 5A and 5C are graphs of $u'(Y(n,q))Y_n(n,q)$ versus q. If $\eta < \sigma$ at the unregulated equilibrium, then the unregulated price is in the interval $(\bar{p}_1, \bar{p}_2)$, and the unregulated quality in the interval (q_2,q_1). A price ceiling close to the unregulated price discretely reduces quality to a level less than q_2 (specifically, a point on the curve that coincides with the price ceiling measured on the vertical axis) and has no effect on quantity. As noted above, consumers are unambiguously worse off because they are paying essentially the same but getting less quality. Producers are unambiguously better off because their revenue is essentially the same, but they have reduced their average costs by providing less quality. This is yet another result the opposite of the textbook analysis, where it is reported that producer surplus is lost, and consumer surplus is gained, in industries with price ceilings and inelastic supply, at least if the regulated price is close enough to the unregulated. This result does not even require that quality be a particular good substitute for quantity, as long as other goods are an even worse substitute.

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[45] We derive a multiplier for the inelastic supply case by (a) taking the Definition PR, (b) assuming $g(n,q) = n^{1+\gamma}/(1+\gamma)+G(nq)$, and (c) taking the limit as γ goes to infinity, holding constant the marginal cost at the unregulated allocation.

[46] In the more general case that the supply of quantity is at least somewhat sensitive to the price, $\eta < \sigma$ is necessary but not sufficient for $\beta > 1$. Or to put it another way, $\beta > 1$ means that σ exceeds η by enough to offset the degree to which the willingness to pay for n decreases with n.

IV. Who benefits from price and quality ceilings?

Beginning from an allocation with $\beta > 1$, introducing a price ceiling close to the unregulated price, or marginally tightening one, results in discretely less consumer and social surplus and discretely more producer surplus. The purpose of this section is to also address the cases in which $\beta < 1$ and/or the price or quality ceiling is not necessarily near the unregulated equilibrium value. The two are related because a ceiling that is discretely below the unregulated value can be achieved by introducing a ceiling close to the unregulated value, followed by a sequence of marginal reductions in that ceiling.

The marginal cost curve $g_n(n,q)$ drawn in the $[n,p]$ plane (see Figure 3A) is shifted down by a quality ceiling, or by a price ceiling that results in less equilibrium quality. As shown in Figure 7, the equilibrium price change is a combination of the vertical distance $g_{nq}(n,q)dq$ of the marginal cost shift and the movement along that curve, which can be in either direction. Supposing for the moment that regulation has no quantity impact (i.e., $\beta = 0$), as at Figure 7's bottom circle, then producers are losing revenue $nd\bar{p} = ng_{nq}(n,q)dq$ but saving the total costs $g_q(n,q)dq$ that are shaded in the figure.[47] By our Assumption B, the net cannot be positive. Because movements down the marginal cost curve (i.e., $\beta < 0$) further reduce revenue more than total costs, it follows that producers cannot benefit from ceiling regulations without $\beta > 0$ at enough of the allocations between the regulated and unregulated allocations that the net impact on quantity is positive.

[47] Although Figure 3B, which graphs supply and demand in the $[Y,\lambda]$ plane, is effective for measuring social surplus, it is less effective for measuring the allocation of surplus because the equilibrium shadow price is not necessarily what consumers pay sellers per unit Y. The latter does occur, however, when production function takes the form $Y(n,q) = ny(q)$, so that the shadow price $\lambda = p/Y_n$.

Now consider a quality ceiling that increases quantity enough that there is no price impact, as at the allocation R_0 in the figure. Here there is no change in revenue, but a reduction in costs. It follows that *producers cannot lose*, and consumers cannot gain, from quality ceilings unless $\beta < 1$ at enough of the allocations between the regulated and unregulated allocations that the net impact on price is negative. As shown in Section III, the same reasoning applies to the marginal tightening of a price ceiling: producers benefit and consumers lose unless $\beta < 1$.

For discrete changes in a price ceiling or, when $\beta \in (0,1)$, marginal changes in either type of ceiling regulation, the producer's benefit cannot be signed without more information about regulation's relative impacts on revenue and costs. The cost savings on the unregulated quantity is $g_q(n,q)dq$, while the corresponding revenue loss is $n_u dp$.[48] If we define β for discrete regulation changes the same way that we do for marginal changes – as the ratio of equilibrium price change to the amount of the shift of the marginal cost curve measured in the price dimension – the revenue loss on the unregulated quantity is $(1-\beta)n_u g_{nq}(n,q)dq$. Using our definition (2) of θ, the cost savings exceed the revenue loss if and only if:

$$\beta > \frac{1}{1+\theta} \tag{20}$$

The inequality (20) is a necessary and sufficient condition for producers to benefit from ceiling regulations, and a sufficient condition for consumers to lose.[49] Whenever producers gain from a tighter ceiling, consumers lose because the ceiling reduces total surplus.

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[48] Costs and revenue on the increment $(n_r - n_u)$ to quantity are essentially zero because price equals marginal cost.

[49] Murphy (1980) has a characteristics model of the supply side in which producers can benefit from price ceilings. In the rent control context, Autor, Palmer and Pathak's (2014) empirical results suggests that price ceilings in Cambridge, Massachusetts harmed producers. But note that Cambridge rent control enforcement included conscription – such as the taking of properties by the power eminent domain (Mulligan 2015) – which is not part of our model of price ceilings.

Notice that the inequality (20) includes θ, which we have called the "elasticity of supply of quality." The unregulated equilibrium maximizes social surplus, but not producer surplus (producers compete!), which opens the possibility that regulation could change the mix of quantity and quality in a way that benefits producers. When quality is elastically supplied (θ large), producers are not harmed much by the quality reduction, and can make up for it if their production of quantity sufficiently expands (β large).

The two directional possibilities are shown with black and blue curves in Figure 6. Both curves exhibit a first-order impact on producer surplus, by which we mean that, at the unregulated equilibrium, the marginal effect of reducing the ceiling is not zero. But producers gain from a tighter ceiling when the inequality (20) holds, which is the case represented by the black curve.

Because $\theta > 0$, Section III.D and the inequality (20) show that a positive β – in other words, either supply is completely inelastic or the quality reduction that results from a ceiling is associated with a quantity increase – is necessary but not sufficient for producers to benefit. This is essentially the opposite of the textbook analysis (see also Bulow and Klemperer (2012)), where quantity reductions are taken as evidence that supply is price elastic and therefore that consumers may be losing from a price ceiling.

V. Conclusions

This paper abstracts from the question of which buyers receive the goods in a regulated market, and previous studies have noted the first-order efficiency losses from the misallocations caused by ceilings. Nevertheless, we find that the welfare costs of price regulation can be worse than first order, and of a different character than the costs of excise taxes or quality regulations, because flexible prices may be needed to prevent beggar-thy-neighbor reactions among the sellers. In effect, producer decisions about non-price product attributes become complementary in the absence of a price mechanism, even though they are not complementary in the unregulated market. The price-regulated equilibrium behavior need not be close to efficient even when the regulated price is.

If Bulow and Klemperer (2012) are correct that price ceilings on average harm both consumers and producers, then the existence of ceilings would suggest that support for the regulation among market participants, if any, would either be misguided or come from subsets of consumers or producers that are different enough from the average. Our model suggests an alternative: that producers may benefit *on average* from a price or quality ceiling because it softens the non-price (a.k.a., quality) competition that would otherwise dissipate some of their surplus. Moreover, markets with relatively inelastic supply are especially likely to feature this type of benefit for producers.

Real-world products have many non-price attributes, and our model is not detailed enough to predict the types and composition of quality adjustments that would occur. But those adjustments could include something like customer "waiting" if it reduces sellers' costs. Take, for example, the inventories that sellers have on hand. Low average inventories mean lower costs but more stock outs and thereby less average value for consumers. A customer encountering a stock out is waiting in the sense that he must defer his purchase until the seller replenishes the inventory (Yurukoglu, Liebman and Ridley 2016). Our model can capture this by treating seller average inventory levels as a non-price attribute q that goes in the customer's production function Y. This approach contrasts with previous models in which, akin to an excise tax, waiting is an additional cost borne in part by buyers but (purportedly) yielding no benefit to sellers (McCloskey 1985, pp. 325-6, Frech and Lee 1987, D. D. Friedman 1990, Figure 17-4, Bulow and Klemperer 2012).

In contrast to the standard analysis of price controls, our model has no random or purely wasteful mechanism for resolving the "shortages" associated with price ceilings. Market participants in our model have no incentive to engage in such schemes, because sellers prefer to adjust non-price attributes in a way that reduces costs and buyers prefer to get a low-quality product than no product at all. Another practical implication of our approach is that regulated-equilibrium quantity and quality reflect both supply and demand conditions, whereas the standard approach says that changes in demand only affect the amount of the shortage without affecting what sellers do. For the same reason, unlike the standard approach, price ceilings can be introduced to markets with elastic supply without reducing quantity much (and may even increase quantity).

We show that quality degradation can either increase or decrease buyers' willingness to pay at a given quantity, and provide an elasticity condition that describes which case applies in any particular situation. Even though strong assumptions are needed to guarantee the latter case, the former is largely absent from the literature, and is the source of some of the "upside-down" results. With lower supply costs and little or no reduction in the willingness to pay, *a price ceiling could increase the quantity traded*, especially when there is an inelastic demand for the services provided by the controlled good. It is even possible that the ceiling increases the services themselves.

More empirical work on these predictions is needed, especially with a framework that is consistent with the discontinuities suggested by the theory. It should also be recognized that price ceilings may increase quantity in competitive markets by mechanisms that have been ruled out in this paper, such as reducing the marginal (but not average) cost of the services Y produced by the controlled good, or income effects, or causing a discrete quantity-quality substitution in a part of the commodity space in which the efficient mix is not unique (Mulligan and Tsui 2016).

With sufficiently inelastic supply, pure non-price competition may have multiple equilibria, and that the transition from one to another might be heuristically described as a quality-degradation spiral with some resemblance to insurance premium "death spiral" models. In these cases, the incidence of price regulations is especially far from the standard analysis. A few studies such as Block and Olsen (1981), and experiences with communism itself, have shown that price ceilings can result in extraordinary quality degradation. Recent advocates of rent control, pointing to the case of modern Germany, also assert that ceilings do not always harm quality (Bourne 2014). Nevertheless, there do not appear to be many statistical analyses of actual price ceilings that formally attempt to confirm the existence of multiple competitive equilibria. Perhaps this absence is due to a paucity of real examples, or merely because this implication of competitive behavior had not yet been developed. But even if it were the former, perhaps understanding this potential of competitive behavior would help regulators to avoid creating any new ones.[50]

The direction of the quantity impact of price controls is sometimes used as a litmus test for whether the controlled market is competitive or not. A ceiling that increases quantity is supposed to reveal noncompetitive behavior and social gains from the ceiling. More work is needed to understand non-price adjustments in imperfect competition settings, but we can already say that, without additional information about tastes and technology, either direction of quantity impact is simultaneously consistent with perfect competition, with social harm, and with consumer harm from price regulations. A price ceiling that increases the quantity traded may only reveal that the market is substituting quantity for quality, and not that sellers were ever holding back supply.

[50] With respect to Gresham's Law, Rolnick and Weber (1986) confirm both possibilities: currency-market regulators often recognize that fixing prices can create multiple equilibria, but that sometimes the low-quality equilibrium is observed for small-denomination currencies.

VI. Appendix I: Equilibrium production of various qualities

The purpose of this appendix is to show that, holding factor prices constant, our household production function Y can be interpreted as the result of optimal purchases of multiple products that have different qualities. The quantity argument of that function is literally the total number of products purchased.

To show this most simply, we assume two products that are combined in a homogenous production function F. Good 1 uses the quantity and quality factors in a fixed proportion, which we take to be one. Good 2 uses none of the quality factor. The overall factor intensity $G(q)$ is therefore good 1's share of total units n consumed. Total household production is:

$$Y(n, q) = n\, F\big(G(q), 1 - G(q)\big) \tag{21}$$

Note that this model has $\sigma(n,q) = 1$ (recall equation (2)). Quality can therefore shift the demand for quantity in either direction, depending on the sign of $\sigma - \eta$.

VII. Appendix II: Additional Theoretical Results

VII.A. Cost function properties

Our results require Assumptions A and B about the derivatives of the cost function $g(n,q)$. The purpose of this Appendix is to prove that the factor-usage setup, repeated below for convenience, is sufficient but not necessary to guarantee those assumptions.

$$g(n,q) \equiv \int_0^n S(Z)dZ + \int_0^{nG(q)} s(z)dz \tag{1}$$

with $n > 0$, $S > 0$, $s > 0$, $G \geq 0$, $S' \geq 0$, $s' \geq 0$, $G' > 0$, and $G'' > 0$. The marginal costs of quantity and quality are:

$$g_n(n,q) = S(n) + G(q)s\big(nG(q)\big) > 0 \tag{22}$$

$$g_q(n,q) = nG'(q)s\big(nG(q)\big) > 0 \tag{23}$$

The second-order derivatives are:

$$g_{nn}(n,q) = S'(n) + [G(q)]^2 s'\big(nG(q)\big) \geq 0 \tag{24}$$

$$g_{nq}(n,q) = \big[s\big(nG(q)\big) + nG(q)s'\big(nG(q)\big)\big]G'(q) > 0 \tag{25}$$

$$g_{qq}(n,q) = nG''(q)s\big(nG(q)\big) + [nG'(q)]^2 s'\big(nG(q)\big) > 0 \tag{26}$$

Factor costs are jointly convex in the factor amounts (n,z). In order to guarantee Assumption D (joint concavity of social surplus in the factor amounts) and that the willingness to pay for quantity (the RHS of (12)) slopes down in quantity at each quality, it is sufficient to assume that output Y is jointly concave in the factor amounts (n,z) and that u is strictly increasing and concave.

VII.B. Price regulations drive a wedge between private and social benefits

A price ceiling drives a wedge between the private and social benefits of supplying quality because factor prices respond to that behavior. Consider a "price-regulated planner" that was choosing quality q and quantity n subject to the constraint that the marginal cost of quantity cannot exceed $\bar{p}$. That planner's Lagrangian is:

$$\mathcal{L} \equiv u\big(Y(n,q)\big) - g(n,q) + [\bar{p} - g_n(n,q)]\lambda \tag{27}$$

The optimal quantity for the price-regulated planner satisfies:

$$u'\big(Y(n,q)\big)Y_n(n,q) = \bar{p} + \lambda g_{nn}(n,q) \tag{28}$$

By comparison, our model's price-regulated equilibrium satisfies:

$$u'\big(Y(n,q)\big)Y_n(n,q) = \bar{p} \tag{29}$$

The price-regulated planner and the market coincide only if (a) both factors are perfectly elastically supplied ($g_{nn} = 0$) or (b) the price regulation is not binding ($\lambda = 0$). The price-regulated planner's decision considers the fact that quantity choices affect the cost of compliance, whereas the decision of an individual seller (subject to regulation) does not.[51]

The price-regulated planner's condition (28) shows that, with special exceptions (a) and (b) noted above, the marginal cost of quantity exceeds $\bar{p} = g_n(n,q)$. In other words, regulated prices fail to reflect all of the relevant marginal costs, and this failure is the source of some of the most damaging market reactions to the regulation. Quality

[51] Conversely, by making the equilibrium condition (12) or (29) rather (28), we assume that the industry's marginal costs are either constant or rising because of factors that are not perfectly elasticity supplied to the industry.

regulation does not fail in this way. If the planner were subject to quality regulation instead, she would be maximizing $u(Y(n,q))-g(n,q)$ with respect to quantity (only), just as the quality-regulated market does.

VII.C. A special case that demonstrates the upside-down results

The cost function, production function, and utility function do not have to be exotic in order to obtain our model's unusual results. Here we assume that the factor supply functions each have a constant elasticity, $S(Z) = Z^{1/\gamma}/A$ and $s(z) = z^{1/\theta}B/A$, with A, B, γ, θ all positive, and the function $G(q)$ to be increasing and convex with an elasticity greater than one. In this case, the cost function is

$$g(n,q) = \frac{\gamma}{1+\gamma}\frac{n^{(1+\gamma)/\gamma}}{A} + B\frac{\theta}{1+\theta}\frac{[nG(q)]^{(1+\theta)/\theta}}{A} \tag{30}$$

We also take the marginal rate of substitution function $u'(Y) = 1 - Y$ to be linear on the range $Y \in [0,1]$ and the production function to be $Y(n,q) = nq$. In this case, the willingness to pay for quantity is $(1-nq)q$. The magnitude η of the price elasticity of Y-demand is less than one, and therefore less than the elasticity of substitution $\sigma = 1$, at any allocation with $Y > ½$. It follows that, beginning at any such allocation, reducing quality will increase the willingness to pay for quantity.

The expansion path in the $[n,q]$ plane is described by:

$$[qG'(q) - G(q)][G(q)]^{1/\theta}B = n^{1/\gamma - 1/\theta} \tag{31}$$

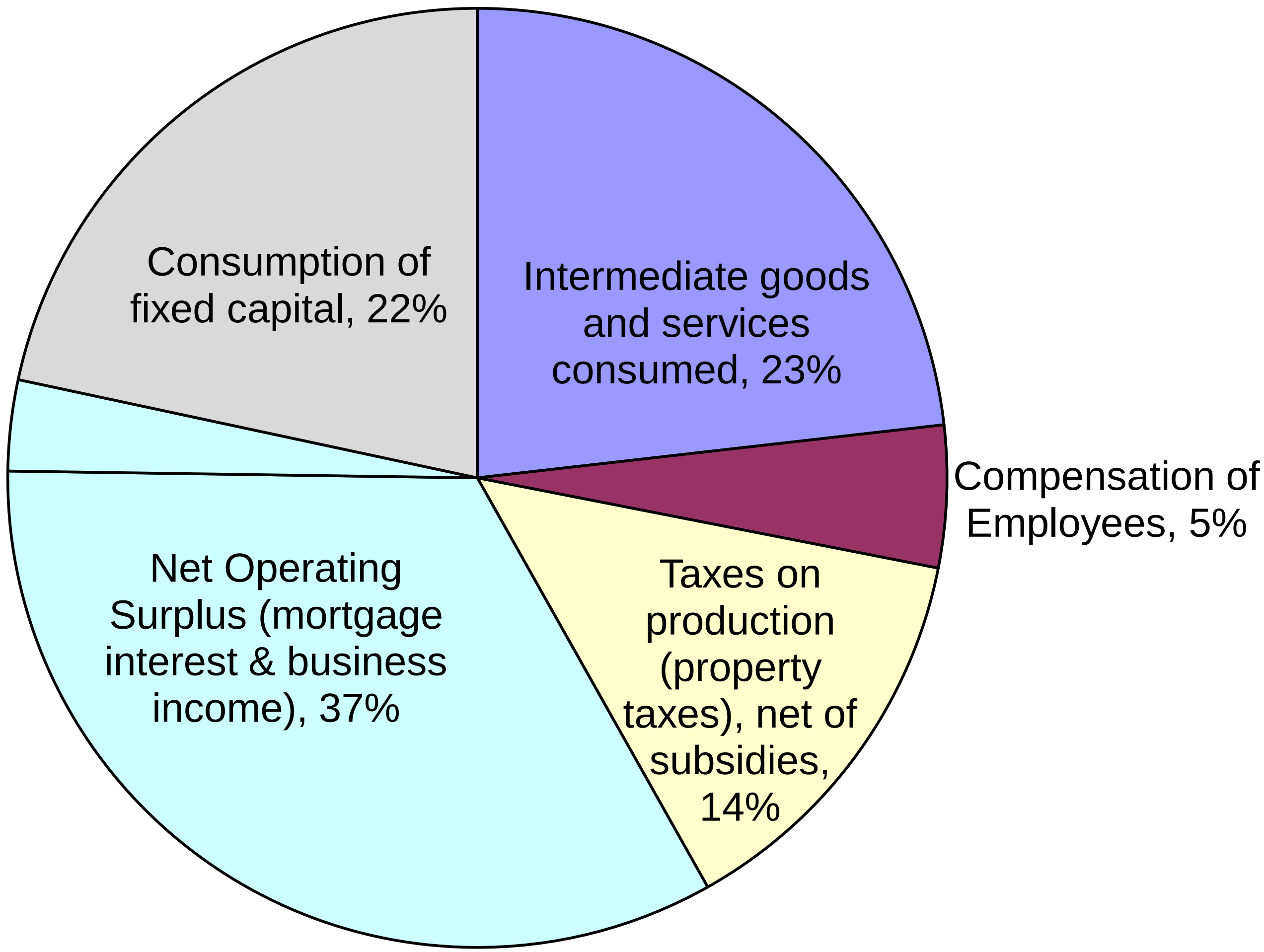
The expansion path therefore can have a slope of either sign, which is the same as the sign of $(\theta-\gamma)$. If $\theta < \gamma$, then a quality ceiling sufficiently close to the unregulated quality results in more equilibrium output Y.

The market multiplier β can exceed one at the unregulated allocation. Take the special case of the cost function (30) that has a perfectly elastic supply of the quality factor Z and an elasticity of supply of the quantity factor z that is 1/2:

$$g(n,q) = \frac{1}{5}\left(\frac{16}{27}n^3 + \frac{nq^5}{4}\right) \tag{32}$$

The efficient allocation is $n = ¾$ and $q = 1$. At this allocation, the marginal cost g_n is ¼, the elasticity of Y-demand is −1/3, and the market multiplier is 24/23. There are three price-regulated equilibria with $g_n = ¼$: the unstable efficient allocation and the stable allocations with (n,q) approximately equal to (0.84,0.36) and (0.74,1.02).

Figure 1. Claims on gross tenant-occupied housing output, 2006



Note: the smaller NOS piece is the part allocated to vacant units.

Figure 2. The demand for raw quantity with a quality ceiling.

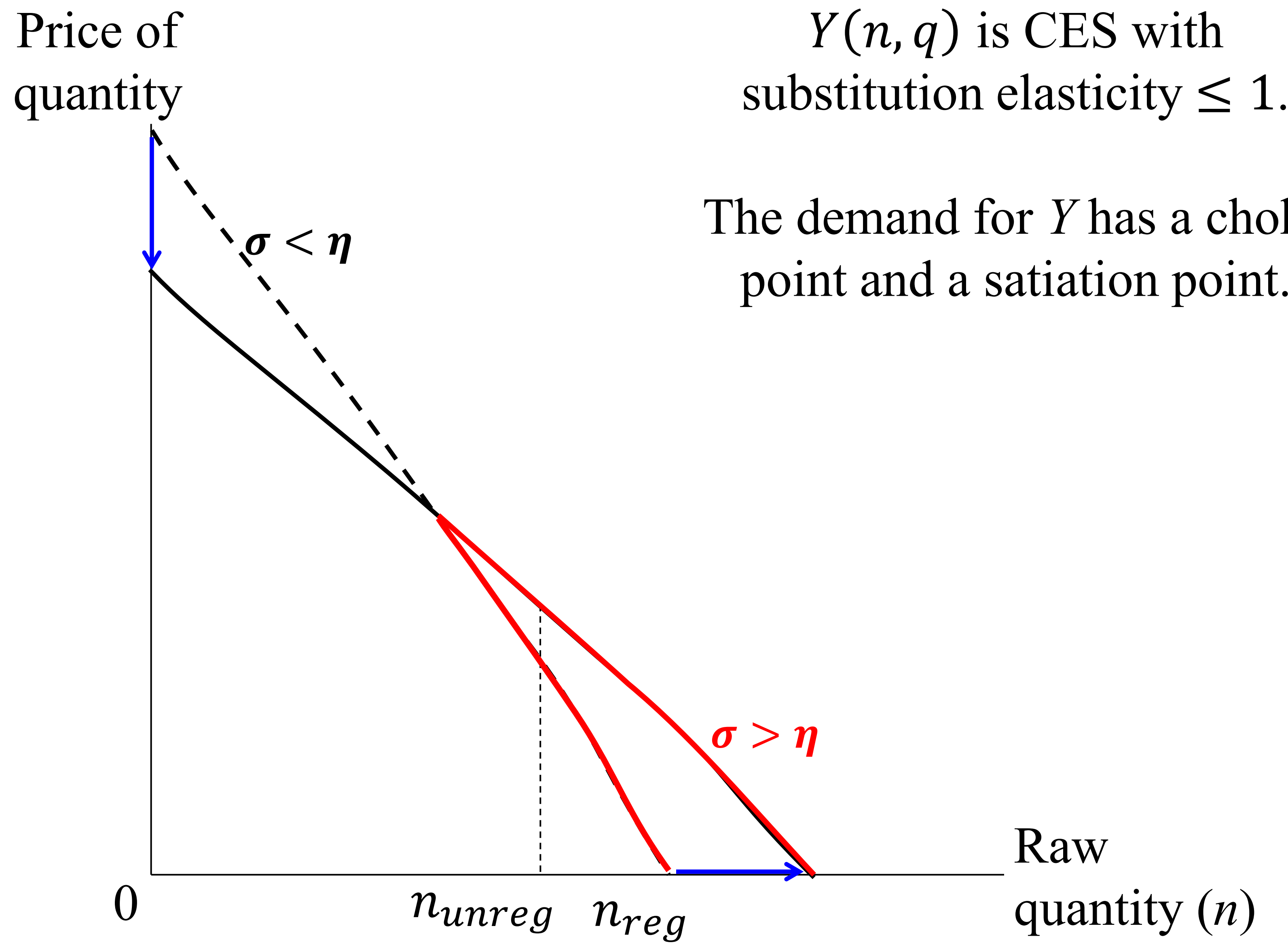


Figure 3A. The raw quantity of the controlled good,
with quality regulation and $\sigma = \eta$ on the relevant parts of demand.

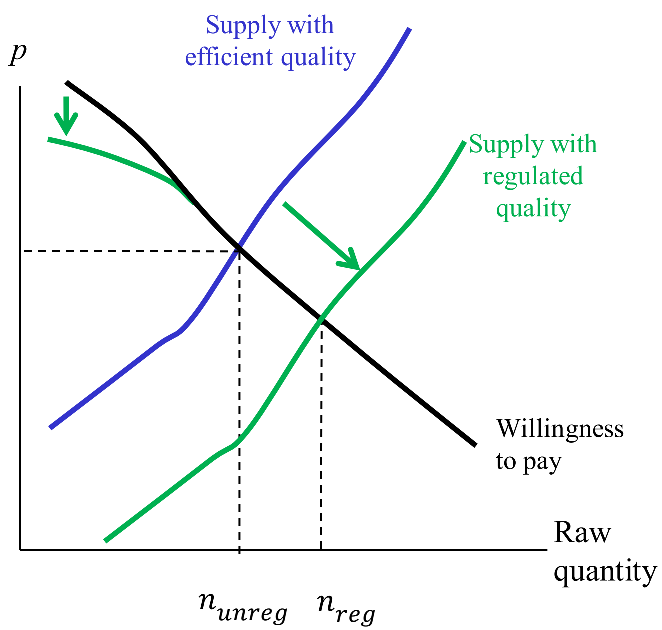


Figure 3B. The services provided by the controlled good,
with separable conditional cost: Y-supply shift is second order.

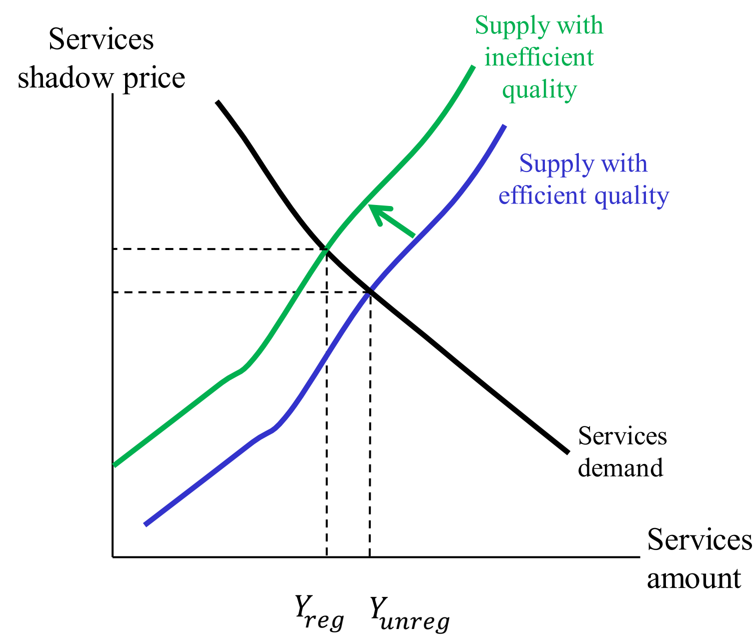
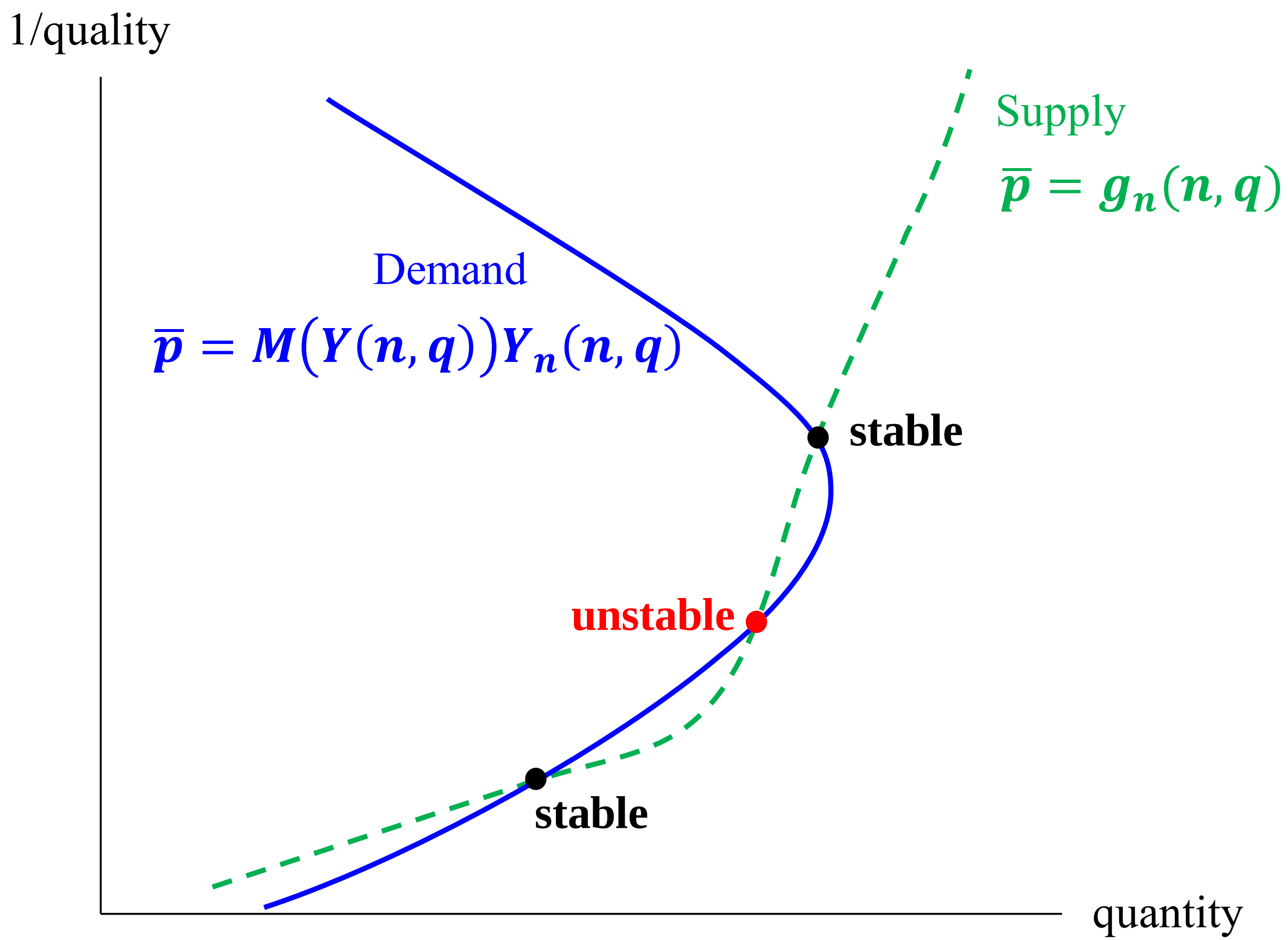


Figure 4. Is quality a pseudoprice?

A market in which $\beta < 1$ at some allocations



Note: $\bar{p}$ is held fixed.

Figure 5A. Equilibrium quality vs. the price ceiling

The role of the market multiplier

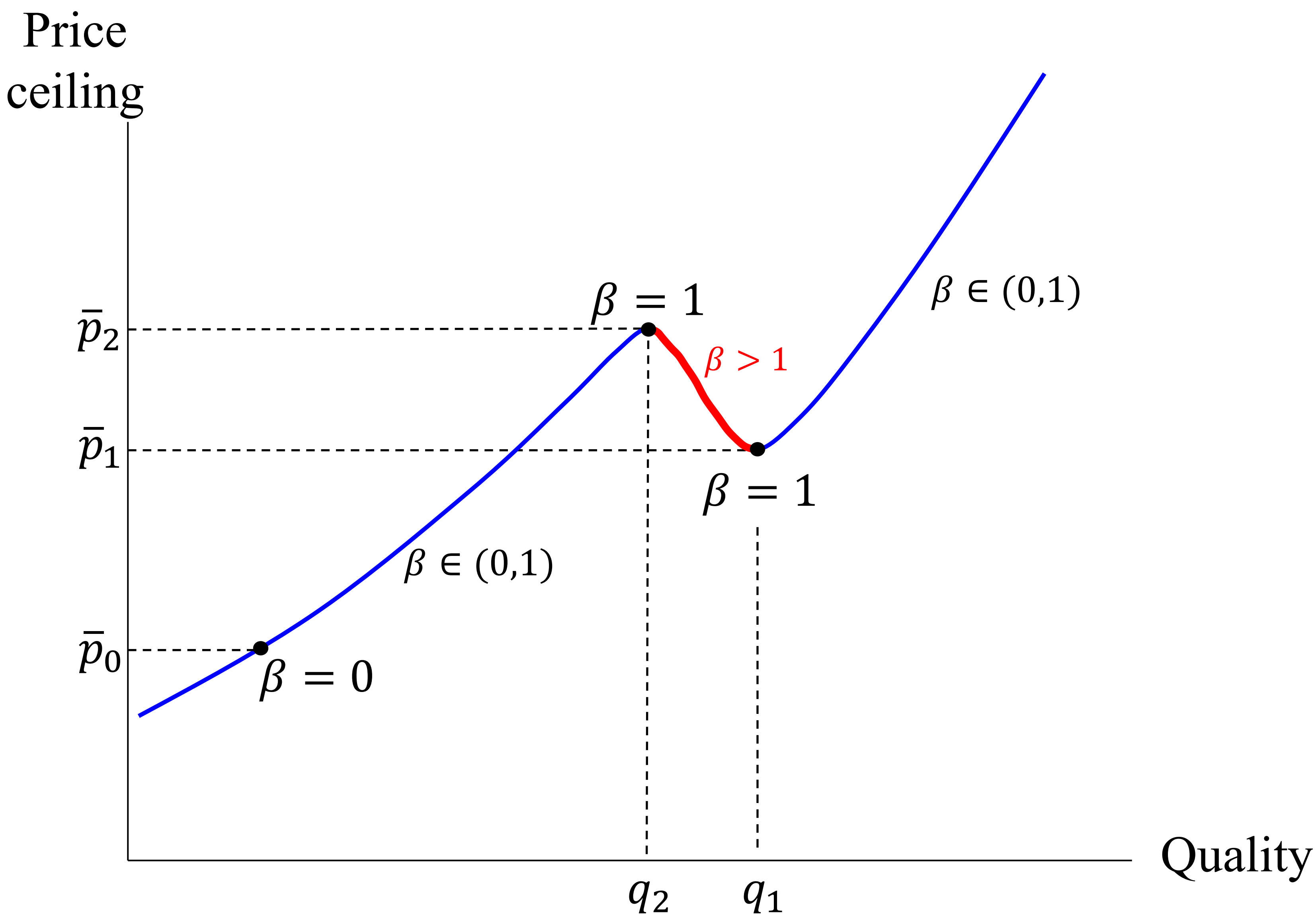


Figure 5B. Equilibrium quantity vs. the price ceiling

The role of the market multiplier, assuming $g_{nn} > 0$

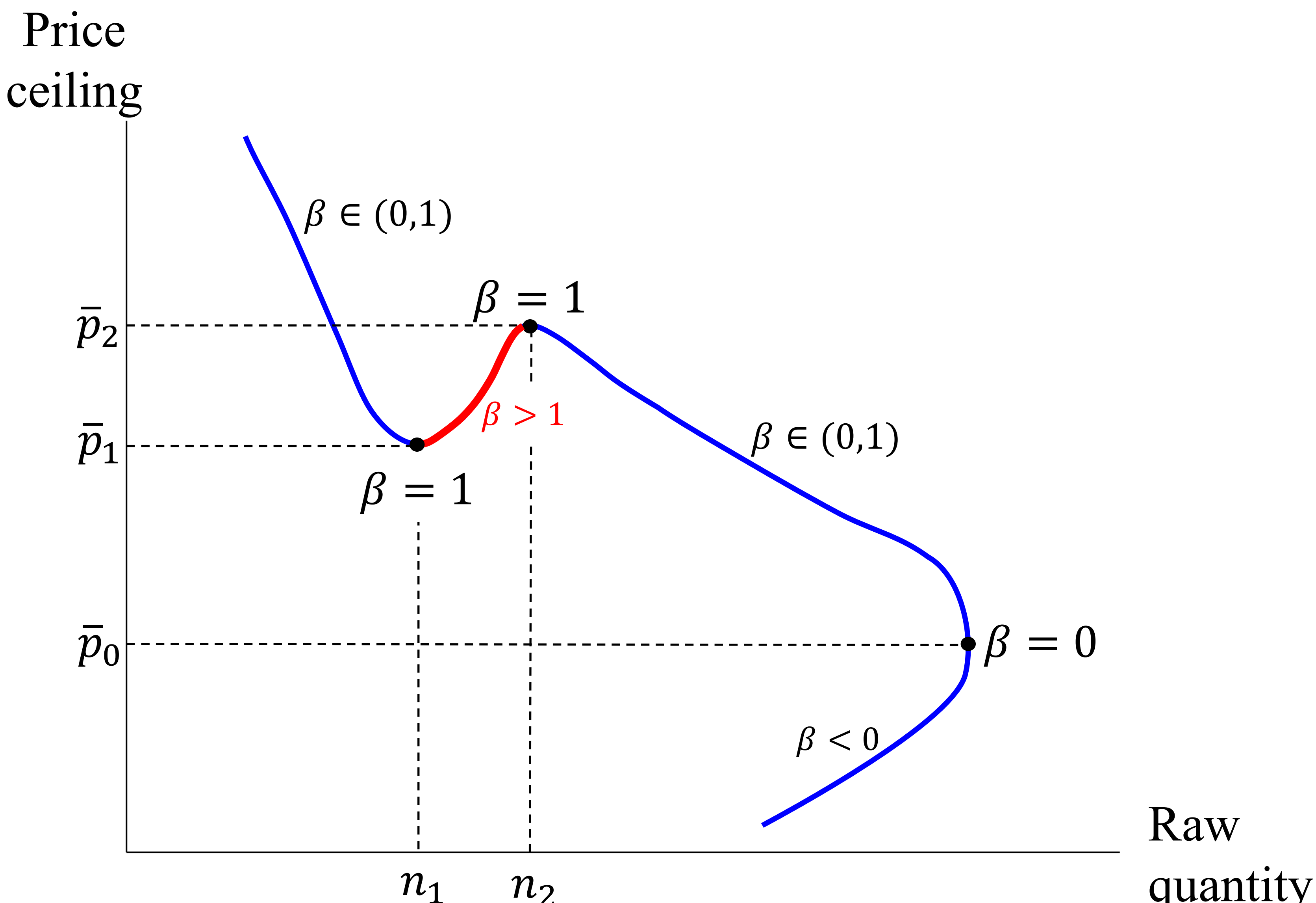


Figure 5C. Equilibrium quality vs. the price ceiling

Example: the multiplier exceeds one at the unregulated allocation

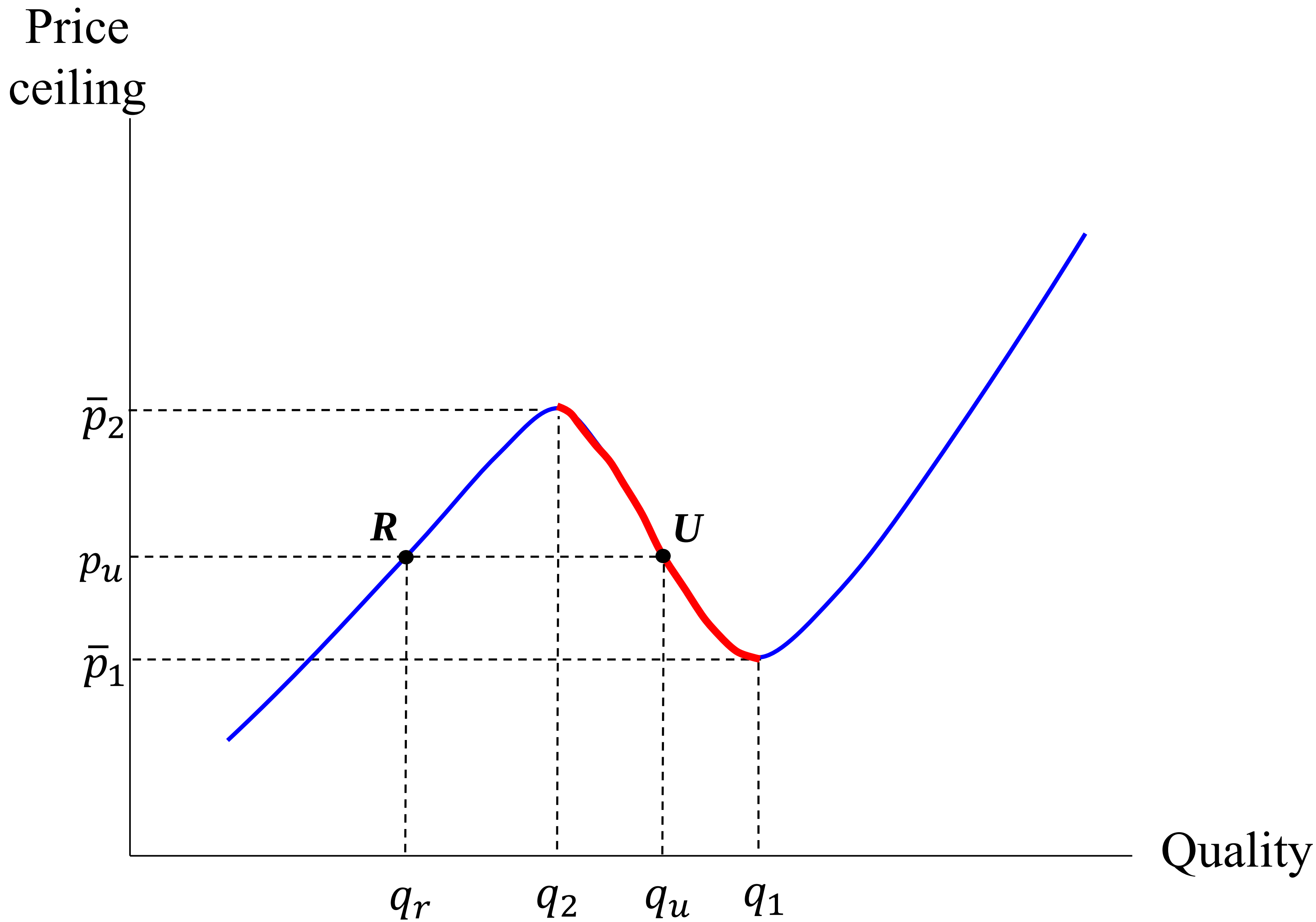
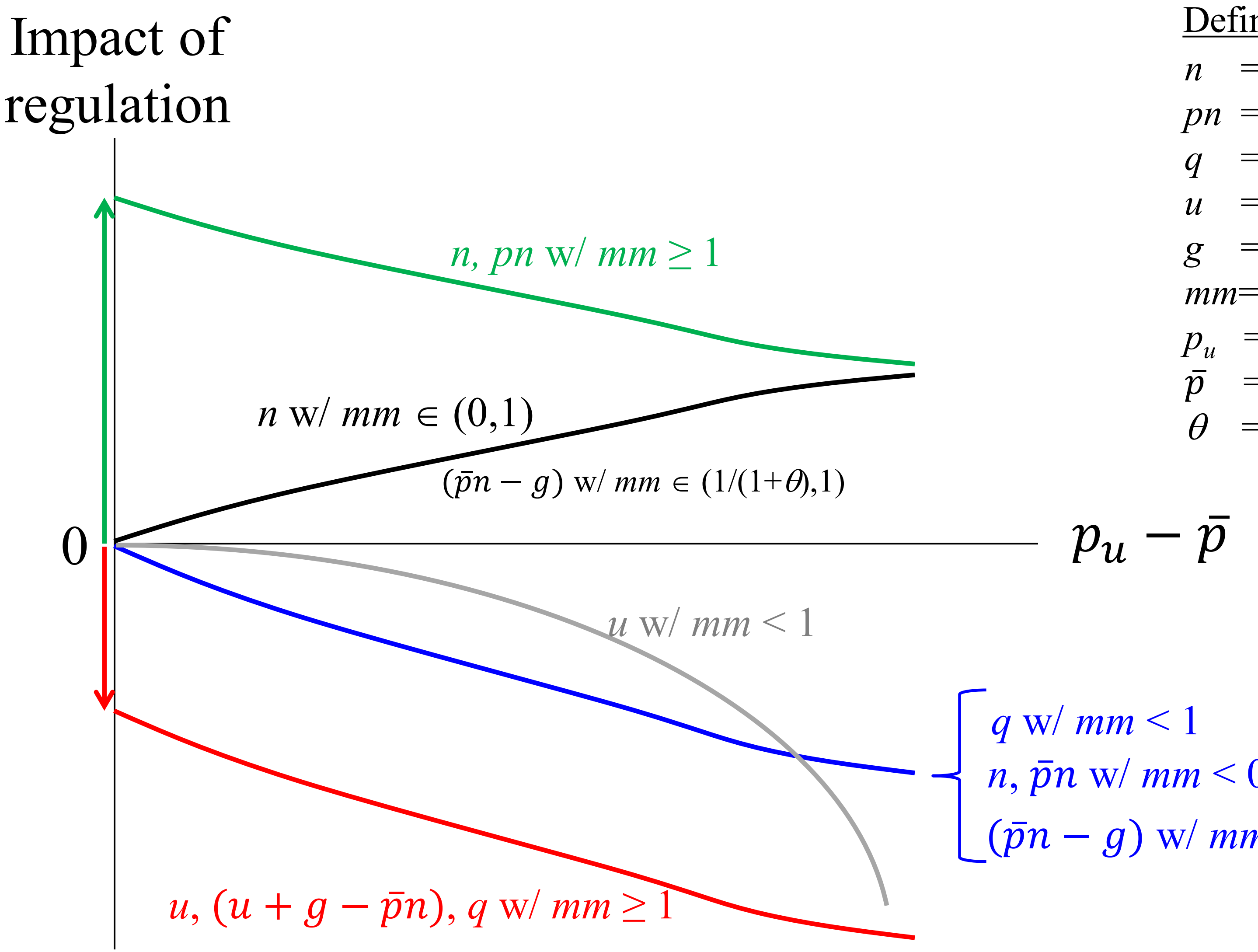


Figure 6. Qualitative effects of price regulation

by the market multiplier value at the unregulated allocation



Definitions

n = quantity
pn = expenditure
q = quality
u = social surplus
g = total cost
mm= market multiplier
p_u = unregulated price
$\bar{p}$ = regulated price
θ = elasticity of q supply

Note: Assumes that supply is not perfectly elastic

Figure 7. Producer surplus
with a quality or price ceiling.

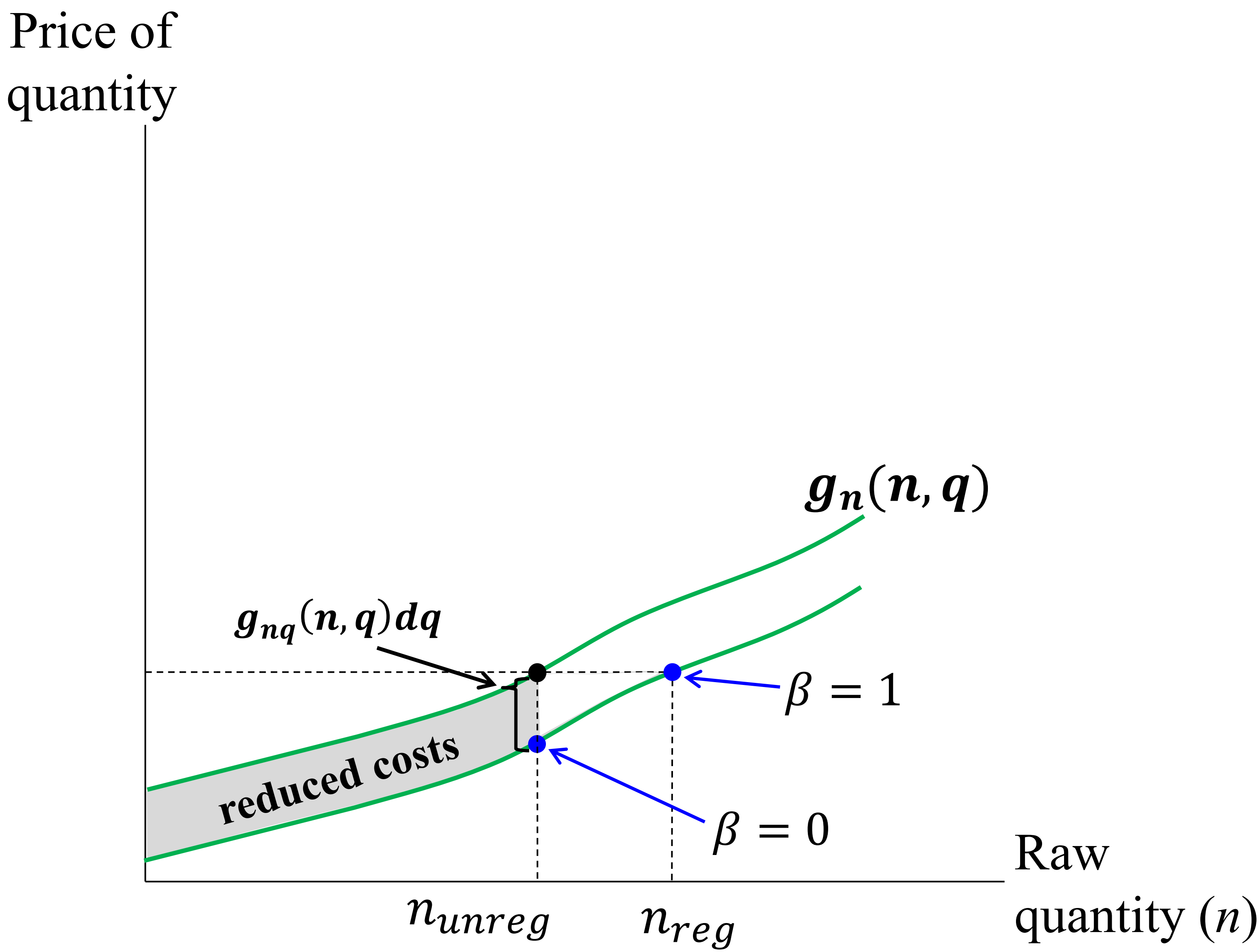
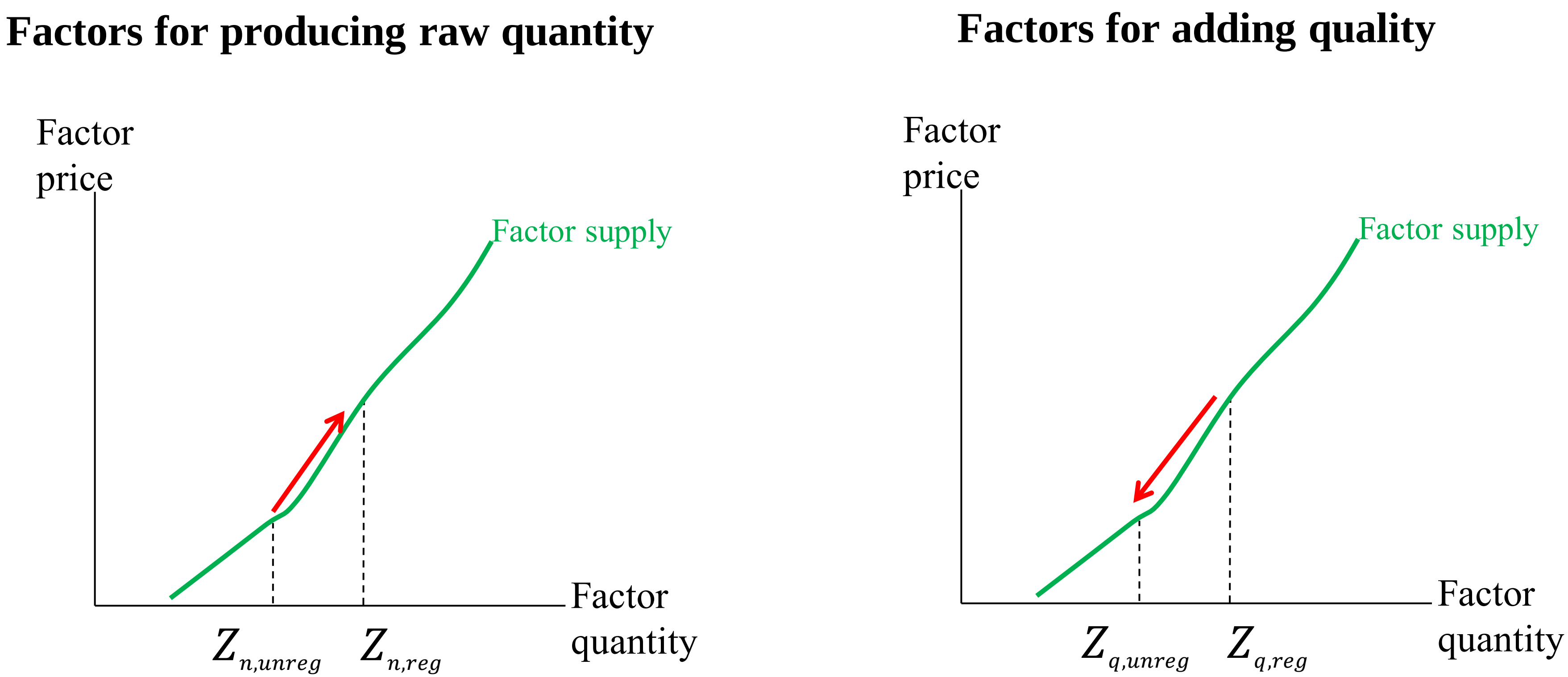


Figure 8. Quality regulation changes the composition of producer surplus.



$$g(n,q) = \int_0^n S_n(Z_n)dZ_n + \int_0^{nG(q)} S_q(Z_q)dZ_q$$

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