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DIVESTING POWER

Giulio Federico

Angel L. López

IESE Business School – University of Navarra
Av. Pearson, 21 – 08034 Barcelona, Spain. Phone: (+34) 93 253 42 00 Fax: (+34) 93 253 43 43
Camino del Cerro del Águila, 3 (Ctra. de Castilla, km 5,180) – 28023 Madrid, Spain. Phone: (+34) 91 357 08 09 Fax: (+34) 91 357 29 13

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DIVESTING POWER

Giulio Federico[1]

Angel L. López[2]

Abstract

We study alternative market power mitigation measures in a model where a dominant producer faces a competitive fringe with the same cost structure. We characterise the asset divestment by the dominant firm which achieves the greatest reduction in prices. This divestment entails the sale of marginal assets whose cost range encompasses the post-divestment price. A divestment of this type can be several times more effective in reducing prices than divestments of baseload (or low-cost) assets. We also establish that financial contracts (modeled as Virtual Power Plant schemes) are at best equivalent to baseload divestments in terms of consumer welfare.

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[1] Public-Private Sector Research Center, IESE and CRA International

[2] Public-Private Sector Research Center, IESE

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1 Introduction

Regulatory and antitrust proceedings often require the application of remedies, in order to mitigate the market power of the affected parties or prevent a reduction in competition from a change in market structure. The appropriate remedy design often plays a critical role in ensuring that competition remains effective in the presence of firms with market power. This paper studies the issue of optimal remedy design in a stylised model that is designed to capture the essential features of the wholesale electricity market. Our analysis focuses on the relative impact of different types of asset divestments, and on the comparison between divestments and financial contracts (in the form of Virtual Power Plants (VPP)). Our framework and results are however applicable also to industries which share some of the basic features of power generation (most notably, a homogenous final product and cost asymmetries between different assets).

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In electricity generation markets, the divestment of actual and/or virtual capacity owned by producers with market power is often employed as a remedy by competition authorities and sector regulators to enhance competition. Outright plant divestments and VPP schemes have been used across Europe in recent times, in the context of merger control proceedings, abuse of dominance investigations, and regulatory reviews of market power in electricity markets. Examples of mergers or joint ventures in the electricity sector where divestments or VPPs have been required by the competition authorities include Gas Natural/Union Fenosa (2009), EDF/British Energy (2008), Gas Natural/Endesa (2006), GDF/Suez (2006), Nuon/Reliant (2003), ESB/Statoil (2002) and EDF/EnBW (2000).[1] Alleged abuse of dominance cases where divestments or VPPs have been implemented as a remedy include proceedings involving E.On (2008), RWE (2008) and Enel (2006). Divestment of generation capacity have also been used by regulators to mitigate market power of incumbent generators in the UK and Italy in the 1990s, whilst in Spain and Portugal regulatory contracts and more recently VPPs have been employed to make the electricity market more competitive.

This paper analyses the competitive impact of divestments and of VPPs in a stylised model of a wholesale electricity market where a dominant producer faces a competitive fringe with the same cost structure. The aim of the paper is two-fold: to study the differential impact of divestments depending on the costs of the generation capacity that is sold by the dominant firm (and thereby identify the divestment policy which achieves the largest reduction in prices); and to compare the effectiveness of divestments of generation capacity with that of VPPs.

We find that the position of the divested capacity on the marginal cost curve of the dominant firm has a strong effect on the impact that a divestment has on market prices. For sufficiently large divestments, the divestment policy which achieves the greatest reduction in prices is the one which divests marginal plants, whose range of costs encompasses the post-divestment equilibrium price (at a given demand level). A divestment of this type induces the dominant firm to price on the flatter segment of its residual demand curve. Depending on the size of the divestment, the most effective divestment can reduce prices several times more than the divestment of baseload plants and it can lead to competitive pricing. We also find that the optimal divestment always increases total welfare (or efficiency), whilst this is not the case for all types of divestments. Our results on divestments have implications for the assessment of the impact of independent entry, showing that the entry of marginal plants can be significantly more effective in reducing prices than the entry of baseload plants.

The paper compares the optimal divestment policy to VPP arrangements. We abstract in our modelling from some of the potential advantages of VPPs, including the fact that they may be easier and faster to implement than plant divestments, and can be reversed once competitive conditions improve. We also do not model some of the shortcomings of VPPs which have been identified in dynamic settings (e.g. the fact that they may not mitigate market power effectively if VPP auctions

[1] Divestments of generation capacity were also implemented in the British market in the context of two mergers involving the incumbent generators and retail suppliers during the 1990s.

are repeated over time, thereby potentially giving incentives to producers with market power to increase spot prices to affect future VPP revenues).

We model VPPs as a set of several call options on the output of the dominant firm with different exercise prices. We establish that VPPs are always weakly less effective than plant divestments in reducing prices and they can at best replicate the impact of a baseload divestment (if the strike prices are set sufficiently low, implying that the VPP works like a forward contract). This result implies that setting the strike prices of a VPP so as to mimic the variable costs of marginal plants does not increase the effectiveness of the remedy. In particular, it does not ensure that the sale of virtual plants will be as effective as the corresponding divestment of generating capacity in reducing prices.

There is a relatively limited literature on the impact of divestments and VPPs on market power in electricity generation markets, and on their relative effectiveness. Most of the related academic research to date has focused on the impact of forward contracts on market power. This literature is relevant to VPPs since forward contracts can be interpreted as call options which are exercised by the option holder independently of the spot price (i.e. the options are always "in the money"). This strand of the literature was started by the contribution by Allaz and Vila (1993), which established that forward contracts can significantly increase competition in spot markets in a Cournot duopoly model. Newbery (1998), Green (1999), and Bushnell (2007) extend some of the results established by Allaz and Vila to competition in supply functions and Cournot competition with multiple firms, in the specific context of electricity markets.

More recently some papers have noted that the pro-competitive impact of forward contracts in electricity markets may be mitigated in the presence of repeated interaction with or without asymmetric information on the costs of the dominant firms (see Schultz, 2007, and Zhang and Zwart, 2006 respectively), or if contracts are not assigned to the largest firms in the market, in a model with discrete bidding functions (Fabra and de Frutos, 2008). Our paper shows that even in the absence of these circumstances, contracts and/or VPPs are inferior to divestments as an instrument to increase competition in electricity markets.

Willems (2006) is more closely related to our paper. Willems compares the effectiveness of "financial" and "physical" VPPs, where the latter are defined as options for capacity that are directly bid in the market by the option holder (whilst financial VPPs are simply call options which are settled once the spot market clears). He finds that the market is more competitive with physical rather than financial options, due to the assumed impact of physical options on the conjectures made by strategic players. The effect identified by Willems is not present in our framework, since physical and financial options are equivalent in the absence of strategic interaction (which is the case for the residual monopoly setting with a competitive fringe that we adopt). Nonetheless we find that − even in a residual monopoly framework − divestments and VPPs can have a very different impact on market prices, due to the fact that divestments have different properties than physical options and can be significantly more pro-competitive than option contracts.

More generally, the results presented in this paper are related to some of the points noted by Armington *et al.* (2006) and Wolak and McRae (2008). These two articles discuss in qualitative terms how divestments of generation capacity can be utilised to remedy the expected impact of a merger on prices, using the specific example of the proposed Exelon/PSEG merger in the US in 2006. The remedies imposed by the US Department of Justice in that merger focused on divesting 'ability' assets, whose costs were close to the market clearing price, implying that the merged entity faced a low opportunity cost of withholding them from the market. By divesting these plants, the competition authority sought to reduce the incentives of the merging parties to increase prices. The results presented in our paper formalise and extend this intuition, identifying exactly which plants should be divested to maximise the pro-competitive impact of the remedy (for a given demand level). Our results also provide formal support to the relatively commonly-held view in the literature and decision practice on electricity markets that ownership of price-setting assets confers greater market power than ownership of baseload plants, even though both types of assets contribute to the presence of market power (for a discussion see Newbery, 2005, and Federico *et al.* 2008; see also OECD, 2005 for some related results).

The structure of the remainder of this paper is as follows. Section 2 describes the set-up of our model, including a characterisation of the residual monopoly (or pre-divestment) equilibrium. Section 3 solves the case of divestments of intermediate size (which we treat as our benchmark divestment scenario). Section 4 presents our results for VPPs, comparing them to those obtained for intermediate divestments. Section 5 extends our core results to the cases of small and large divestments, whilst Section 6 concludes.

2 Model set-up

We model a market with a dominant electricity firm facing a competitive fringe that offers all of its output at cost.[2] We also assume for simplicity that pre-divestment the dominant firm and the fringe have the same linear and increasing marginal cost function, with slope γ. The marginal cost function can be interpreted as the aggregation of production from several atomistic generation plants with different marginal costs, stacked in 'merit order', from the cheapest to the most expensive. We define marginal costs for each firm i as c_i and output as q_i. We also adopt subscript d for the dominant firm and f for the fringe. Our set-up implies that $c_i = \gamma q_i$ for $i = d, f$.

We also assume that total demand is perfectly price inelastic and takes a value of μ. We assume a constant willingness to pay for consumers that lies above the pre-divestment equilibrium price. This ensures that total and consumer surplus are finite. The assumption of inelastic demand also implies that consumer welfare decreases monotonically with the market price, and that total welfare increases if total production costs decrease.

[2] Whilst this set-up is stylised, it is also a reasonable representation of the competitive structure of a number of European power markets, including Belgium, France, Ireland, Italy, and Portugal. Our set-up is also directly applicable to the competitive residual demand framework recently proposed by Gilbert and Newbery (2008) for the evaluation of mergers in the electricity sector.

2.1 Pre-divestment equilibrium

For a given price p, the competitive fringe always produce at its marginal cost: $p = c_f = \gamma q_f$, where $q_f = \mu - q_d$, implying that $p = \gamma(\mu - q_d)$.

The dominant firm solves $\max_p \; pq_d - \int c_d dq$, which is equivalent to solving $\max_{q_d} \; \gamma(\mu - q_d)q_d - (\gamma/2)(q_d)^2$. The first-order condition yields:[3]

$$q_d^* = \frac{\mu}{3}; \text{ and } p^* = \frac{2}{3}\gamma\mu$$

where the latter defines the residual monopoly (or pre-divestment) price level.

In the pre-divestment equilibrium the dominant firm therefore serves a third of demand, rather than half of demand as it would in a competitive equilibrium. The quantity between $\frac{\mu}{2}$ and $\frac{\mu}{3}$ is withheld from the market, forcing more expensive generation units owned by the fringe to produce, thereby raising prices and lowering both consumer and total welfare. Note that the competitive price (i.e. the price which would result if all production plants in the market were offered at their marginal cost) is given by $p^c = \frac{1}{2}\gamma\mu$.

2.2 Definition of divestment

We model divestments of generation units that are located contiguously on the marginal cost function of the dominant firm. The maximum output (or capacity) that can be produced by the divested units is defined as δ. This parameter describes the 'size' of the divestment. The marginal cost of the most expensive divested unit is defined as $\overline{c}$. This uniquely defines the 'position' of the divestment on the cost curve of the dominant firm. The marginal cost of the least expensive divested unit is therefore given by $\underline{c} = \overline{c} - \gamma\delta$. For notational purposes we also define q' as follows: $q' = \frac{\overline{c}}{\gamma}$.[4]

Divested generation units are assigned to the competitive fringe and are therefore offered to the market at cost in the post-divestment equilibrium. Relative to the pre-divestment set-up, post-divestment the marginal cost curve of the dominant firm shifts upwards for $c_d > \overline{c} - \gamma\delta$ and its residual demand curve is lower for $p > \overline{c} - \gamma\delta$. It is also flatter than the pre-divestment residual demand function for $p \in (\overline{c} - \gamma\delta, \overline{c})$, whilst for $p \geq \overline{c}$ it has the same slope as the pre-divestment residual demand function, but it is displaced downwards by the size of the divestment δ. The impact of a divestment on the marginal cost and residual demand functions of the dominant firm is illustrated in Figure 1.

The rest of this paper focuses on the impact on market prices (and therefore consumer welfare) of divestments of size δ, depending on their location on the cost curve of the dominant firm (given

[3] The second-order conditions are satisfied throughout the analysis.

[4] This variable defines the total output that the dominant firm would produce in the pre-divestment set-up if the unit with marginal cost $\overline{c}$ were its last (or marginal) unit to be offered to the market and accepted for production. It can also be interpreted as a quantity index along the cost curve of the dominant firm, which also describes the position of the divested segment (in terms of quantities rather than costs).

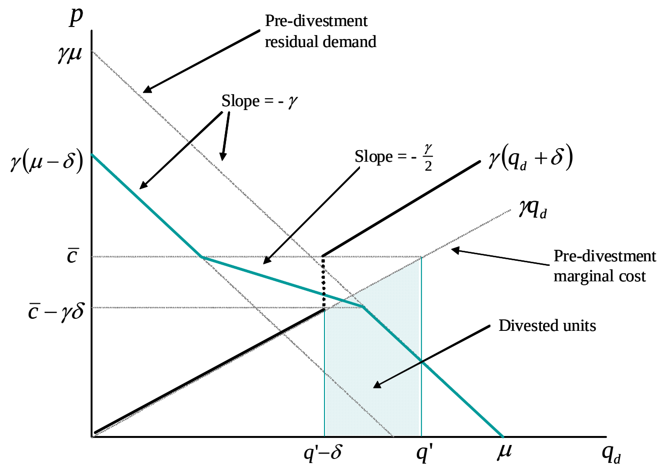

Figure 1: Description of the model set-up and of the impact of a divestment.

by $\overline{c}$). We primarily concentrate on consumer welfare rather than total welfare in our assessment of divestments given that competition authorities and sector regulators are typically concerned with policies which benefit consumers. We however also comment on the welfare implications of alternative divestment policies.

We rely on this set-up to model also the impact on prices of VPPs. VPPs are analysed as call options that are structured so as to mimic a given plant divestment. That is, we consider a bundle of call options of total size δ with contiguous strike prices ranging from $\overline{c}$ to $\overline{c}-\gamma\delta$. This modelling assumption is set out in more detail in Section 4 below.

3 Divestments of intermediate size

In this section of the paper we model divestments of intermediate size, defined as cases where δ, expressed as a ratio of total demand μ (i.e. $\frac{\delta}{\mu}$), lies between $1-\frac{12}{5\sqrt{6}} \approx 0.02$ and $1-\frac{2}{\sqrt{6}} \approx 0.18$. This is a relative wide range for the divestment, which we feel captures most realistic scenarios.[5] In Section 5 below we extend our results also to cases with smaller and larger divestments.

[5] For example, in the case of the Spanish wholesale electricity market which had average demand in 2007 of approximately 30GW, the range for the divestments that we consider here is between 0.6GW and 5.5GW (evaluated at average demand). As a comparison, the total size of the VPP imposed on the two largest producers (Endesa and Iberdrola) in 2008 and 2009 reached roughly 2.5GW, and that of the plant divestments ordered by the Spanish government in two recent domestic mergers (the proposed merger between Gas Natural and Endesa, and the approved merger between Gas Natural and Union Fenosa) were of 4.2GW and 2 GW respectively (see Federico *et al.* 2008).

Another example of divestments is provided by the merger between EDF and British Energy in the British market, where the European Commission imposed a divestment of 2.8GW of generation capacity in December 2008. This is equivalent to roughly 0.07 of average electricity demand in Great Britain, which is also within the range of intermediate divestments that we consider.

3.1 Prices with divestments of intermediate size

The following Proposition describes the post-divestment price function for divestments of intermediate size, as a function of the position of the divested plants. As we show, a unique optimal divestment can be identified. The optimal divestment is defined as the one that leads to the lowest price (and therefore the highest level of consumer welfare) in the post-divestment equilibrium.

Proposition 1 (Intermediate divestments) *The post-divestment price function depends on the position of the plant divestment (denoted by $\overline{c}$). This function (defined as $p(\overline{c})$) has 6 distinct segments provided that $1 - \frac{12}{5\sqrt{6}} < \frac{\delta}{\mu} \leq 1 - \frac{2}{\sqrt{6}}$:*

Segment	*Price*	*Range of $\overline{c}$*
I (baseload)	$p^* - \Delta_p$	$\gamma\delta \leq \overline{c} < \gamma\left(\frac{\mu+\delta}{3}\right)$
II	$\gamma\mu - \overline{c}$	$\gamma\left(\frac{\mu+\delta}{3}\right) \leq \overline{c} < \gamma\left(\frac{\mu+2\delta}{3}\right)$
III	$p^* - 2\Delta_p$	$\gamma\left(\frac{\mu+2\delta}{3}\right) \leq \overline{c} < \gamma\left(\frac{2\sqrt{6}}{3} - 1\right)(\mu - \delta)$
IV	$\frac{3}{8}(\gamma(\mu - \delta) + \overline{c})$	$\gamma\left(\frac{2\sqrt{6}}{3} - 1\right)(\mu - \delta) \leq \overline{c} < \gamma(\frac{3}{5}\mu + \delta)$
V	$\overline{c} - \gamma\delta$	$\gamma(\frac{3}{5}\mu + \delta) \leq \overline{c} < p^* + 3\Delta_p$
VI	p^*	$\overline{c} \geq p^* + 3\Delta_p$

where $\Delta_p \equiv \frac{\gamma\delta}{3}$.

The optimal divestment is given by setting $\overline{c} = \hat{c} \equiv \gamma\left(\frac{2\sqrt{6}}{3} - 1\right)(\mu - \delta)$, which defines the lower bound of segment IV of the post-divestment price function. The optimal divestment achieves the competitive price p^c at the upper end of the range for the size of the divestment considered in this Proposition (i.e. if $\frac{\delta}{\mu} = 1 - \frac{2}{\sqrt{6}}$). Otherwise it yields a price that is between p^c and p^*.

Proof. See Appendix A.1. ■

The post-divestment price function is shown in Figure 2, as a function of the position of the divestment $\overline{c}$. As the figure illustrates this function lies below the pre-divestment price p^* for divestments that are sufficiently competitive, which is the case for $\overline{c}$ sufficiently low (i.e. $\overline{c} < p^* + 3\Delta_p$).

The six segments in the post-divestment price function can be understood by reference to the impact of a divestment on the cost and demand of the dominant firm. As we noted above, a divestment increases the cost function of the dominant firm above a given marginal cost level (i.e. for $c_d > \overline{c} - \gamma\delta$). This can be defined as a *cost-increasing* effect. This effect is relevant to equilibrium pricing for divestments of production capacity whose marginal cost is sufficiently low (implying that the dominant firm is utilising at least part of the divested capacity in the pre-divestment equilibrium). Note that the presence of the cost-increasing effect tends to reduce the pro-competitive impact of a divestment because it induces the dominant firm to set higher prices, ceteris paribus, since its costs are higher.

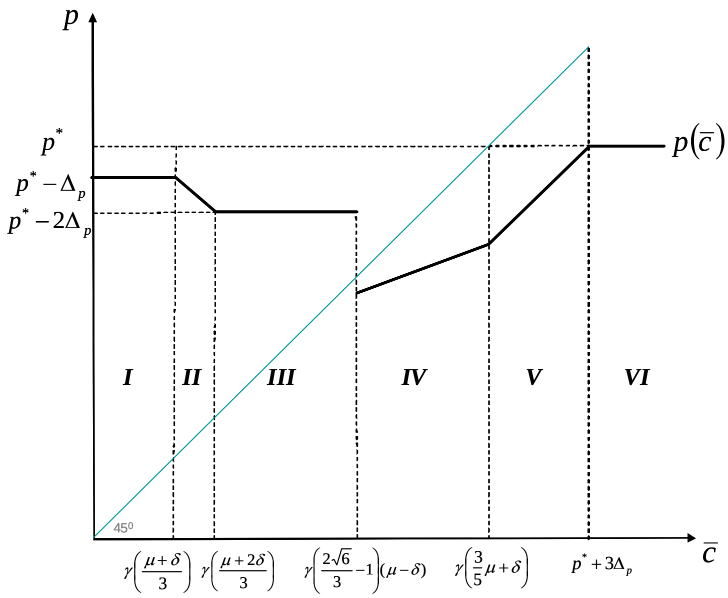

Figure 2: The post-divestment price as a function of the position of the divestment on the cost curve of the dominant firm (for divestments of intermediate size).

A divestment also changes the residual demand curve of the dominant firm, introducing a flatter segment, and also displacing it downwards by the size of the divestment δ for sufficiently high price levels (i.e. $p > \overline{c}$), as it is shown in Figure 1. We term the first demand effect a *demand-slope* effect, whilst the second demand effect is termed a *demand-shift* effect.

The four segments of the post-divestment price function where interior equilibria exist (these are segments I, III, IV and VI – see Appendix A.1) display different combinations of these three possible cost and demand effects, and differ depending on which of the three effects are relevant to the conduct of the dominant firm in the post-divestment equilibrium:

- In segment I (which relates to divestment of low-cost, or baseload, units) the cost-increasing and the demand-shift effects apply, leading to a price reduction since the second effect outweighs the first. The effect of the divestment in this segment is equivalent to the imposition of a forward contract of size δ on the producer, as we show formally in Section 4.

- In segment III, the demand-shift effect applies, but not the cost-increasing one, since the divested units are relatively expensive and include capacity which the dominant firm would have not utilised in the post-divestment equilibrium even if it had been available. The cost of the divested units is however sufficiently low for the divested capacity to be fully utilised by the competitive fringe, which in turn reduces the residual demand faced by the dominant firm by δ. The price reduction from the divestment is therefore larger than in segment I (more precisely, it is twice as large) since the cost-increasing effect is absent.

- In segment IV, the demand-slope effect applies instead of the demand-shift effect since the cost of the divested units is sufficiently high so as to make it profitable for the dominant firm to price on the flatter segment of its residual demand curve (rather than withholding more output, and pricing on the steeper part of the curve). As long as the divestments located within segment IV are sufficiently competitive (i.e. for $\overline{c}$ low enough), pricing on the flatter part of the demand curve has an output-expansion effect and yields lower prices relative to segment III of the post-divestment price function.

- In segment VI, none of the three effects identified above apply, since the divested units have marginal costs that are too high to constrain the pricing of the dominant firm. The post-divestment price is therefore the same as the residual monopoly price p^*.

The other two segments of the post-divestment price function (segments II and V) are corner solutions (as is also explained in Appendix A.1).

- In segment II the demand-shift effect applies and the dominant firm produces on the post-divestment cost function. The cost-increasing effect is present here since the dominant firm cannot produce the optimal output implied under segment III because at that output level its costs would increase relative to the pre-divestment equilibrium. The dominant firm therefore selects an output level that is exactly equal to $q' - \delta$ (i.e. the quantity corresponding to the first generation unit that is divested), and does not utilise any of the units that are more expensive than the divested capacity.

- In segment V the dominant firm prices on the second kink of its residual demand curve, i.e. where the flatter segment of the curve intersects the original pre-divestment residual demand function. The price is therefore equal to the lowest cost of the divested capacity (i.e. $p = \overline{c} - \gamma\delta$), implying that none of the divested units produce in the post-divestment equilibrium. This price is below the monopoly price since at that price some of the divested units would be able to produce. In order to avoid the reduction in its demand that would result if the divested capacity were to produce some output, the dominant firm finds it optimal to price on the second kink of its residual demand curve. It therefore increases its output and lowers its price compared to the pre-divestment outcome, thus ensuring that none of the divested units produce in the post-divestment equilibrium.

3.2 Characterisation of the optimal divestment of intermediate size

Proposition 1 establishes that the divestment which yields the largest price reduction relative to the pre-divestment equilibrium is the one given by the lowest-cost divestment on segment IV. This is the segment where the dominant firm prices on the flatter part of its residual demand curve. This optimal position for the divested capacity (defined as $\overline{c} = \widehat{c}$ above) results in the lowest post-divestment price because it induces the dominant firm to drop its price in order to capture more output from the competitive fringe, and prevent some of the divested capacity from producing. At the optimal divestment, the range of costs of the divested capacity encompasses the post-divestment price, implying that the divested plants are marginal (or price-setting), and that some of divested capacity does not produce in equilibrium.

The highest marginal cost of the optimally divested capacity is below the pre-divestment price.[6] Moreover, the cost range of the optimal divestment lies above both the costs of the cheapest units withheld by the dominant firm in the pre–divestment equilibrium, and the competitive price p^c.[7] If one thinks as the cheapest withheld units as the marginal, or price-setting units, of the dominant firm in the pre-divestment equilibrium (e.g. as would be the case if the dominant producer was constrained to offer a linear supply function for its output), this condition implies that the optimal divestment needs to include units which are bid above the pre-divestment price (i.e. they are outside the competitive margin), but which become price-setting post-divestment when they are owned by the competitive fringe. The figure presented in Appendix A.7 provides an illustration of the position of the optimal divestment for the case of $\frac{\delta}{\mu} = \frac{1}{20}$.

The following Corollary summarises the main characteristics of the location of the optimal divestment.

Corollary 1 (Characteristics of the optimal divestment) *In the case of intermediate values of δ, to achieve an optimal divestment the highest cost of the divested capacity needs to be located between the competitive and the pre-divestment price, that is: $\hat{c} \in (p^c, p^*)$.*

Marginally cheaper divestments than the optimal divestment have a lower pro-competitive effect (even if they do not include baseload plants, as it is the case in segment III of the post-divestment price function). This is due to the fact that the price which the dominant firm would need to accept to exclude some of the divested capacity from the market is too low. In this case the dominant firm finds it optimal to set a higher price and accept a larger reduction of its residual demand. Marginally more expensive divestments than the optimal divestment are also less effective, since they put less competitive pressure on the dominant firm (i.e. a lower price reduction is required to prevent at least some of the divested capacity from producing).

3.3 Implications for the impact of exogenous entry on prices

The price results obtained above also have some implications for the impact of entry by independent firms on market prices.[8] Assume for simplicity that new capacity of size δ belonging to the competitive fringe can enter the market, with marginal costs ranging from $\bar{c}$ to $\bar{c} - \gamma\delta$, along a linear cost function of slope γ. Entry of this type shifts the residual demand function of the dominant firm in the same way as a divestment but does not affect its cost curve. Its impact on prices is therefore the

[6] This follows directly from the fact that $\hat{c} \equiv \gamma\left(\frac{2\sqrt{6}}{3} - 1\right)(\mu - \delta)$ approximates to $0.63\gamma(\mu - \delta)$ which is below $p^* = \frac{2}{3}\gamma\mu$.

[7] The former follows from the fact that $\hat{c} \geq \gamma(\frac{\mu}{3} + \delta)$ (which is shown in Appendix A.1). The latter derives from the fact that $\hat{c} > \frac{\gamma\mu}{2}$, which is the case for $\frac{\delta}{\mu} < \frac{4\sqrt{6}-9}{4\sqrt{6}-6}$ (which is satisfied in the case of intermediate divestments).

[8] This discussion assumes that entry decisions and the cost of new capacity are exogenous.

same as that obtained with a divestment, as long as the dominant firm prices on its pre-divestment cost function (i.e. its costs do not increase relative to the pre-divestment equilibrium). This is the case in segments III to VI of the post-divestment price function.

Proposition 1 therefore effectively establishes that entry of low-cost (or baseload plants) of capacity δ leads to a price reduction equal to the one given in segment III, since in this segment of the post-divestment price function the residual demand faced by the dominant firm shifts by δ and the dominant firm does not price on the flatter part of its residual demand. Entry can therefore be defined as baseload in our set-up as long as the highest cost of the new capacity entering the market is strictly below $\hat{c}$. However, entry can also replicate the impact of the optimal divestment if the highest cost of new capacity of size δ equals exactly $\hat{c}$.[9] Proposition 1 therefore indicates that marginal (or price-setting) entry is more effective than baseload entry in constraining market prices, assuming the cost of the new capacity is determined by the same cost function as the dominant firm.

3.4 Welfare analysis of intermediate divestments

Our assumption of perfectly inelastic demand implies that divestments increase total welfare (or efficiency) if they reduce the total costs of producing the fixed level of output μ. A divestment affects total costs by leading to three distinct output effects: (i) a reduction in the output of high-cost capacity owned by the fringe (which takes place as long as the divestment leads to a reduction in prices); (ii) an increase in output by the divested units (which occurs as long as the post-divestment price is above the lowest cost of the divested capacity); and (iii) a change in the net output of the dominant firm (i.e. output net of any part of the divested capacity which was being utilised by the dominant firm in the pre-divestment equilibrium). These three output effects necessarily sum to 0, given the assumption of inelastic aggregate demand.

Using the case of the optimal divestment to illustrate the impact of these three output effects, the change in welfare from the optimal divestment can therefore be expressed as follows:[10]

$$\Delta W(\hat{c}) = \underbrace{\int_{\frac{p(\hat{c})}{\gamma}}^{\frac{2}{3}\mu} \gamma x dx}_{\substack{\text{cost saving} \\ \text{competitive fringe}}} - \underbrace{\int_{\hat{q}-\delta}^{\frac{p(\hat{c})}{\gamma}} \gamma x dx}_{\substack{\text{additional cost} \\ \text{divested units}}} - \underbrace{\int_{\frac{\mu}{3}}^{\frac{\mu+\hat{q}-\delta}{4}} \gamma x dx}_{\substack{\text{additional cost} \\ \text{dominant firm}}} .$$

Note that divestments are welfare-increasing as long as they do not induce the dominant firm to

[9] Note of course that entry of capacity with highest cost equal to $\hat{c}$ will not be all used in the market for a given demand level μ. If demand is fixed at μ therefore it will not be profitable to build such capacity. If demand is variable however, then it may be profitable to invest capacity that is price-setting at low or medium demand levels, and that is infra-marginal during high demand levels.

[10] Recall from Proposition 1 that $\hat{c} = \gamma\left(\frac{2\sqrt{6}}{3} - 1\right)(\mu - \delta)$ and that $\hat{q} = \frac{\hat{c}}{\gamma}$. The proof of Proposition 1 also establishes that $\frac{\mu+\hat{q}-\delta}{4}$ is the output of the dominant firm in the case of the optimal divestment.

reduce its net output (as defined above). This follows from the assumption of increasing marginal costs, which in turns implies that both the part of the divested capacity that produces in the post-divestment equilibrium and any net output increase by the dominant firm have lower marginal costs than the capacity of the competitive fringe that no longer produces post-divestment.

The following Proposition summarises the welfare effects of divestments of intermediate size.

Proposition 2 (Welfare) *Divestments of intermediate size are welfare-increasing for all the ranges of* $\bar{c}$ *given in Proposition 1, except for segment III, where* $\bar{c} \in \left[\gamma\left(\frac{\mu+2\delta}{3}\right), \gamma\left(\frac{2\sqrt{6}}{3}-1\right)(\mu-\delta)\right)$. *In this range of the costs of the divested units, divestments can reduce welfare for sufficiently small divestments, i.e. for* $\frac{\delta}{\mu} \in \left(1-\frac{12}{5\sqrt{6}}, \frac{6\sqrt{6}-14}{6\sqrt{6}-7}\right)$.

Proof. See Appendix A.2. ■

The result given in Proposition 2 follows from the fact that - for intermediate divestments - the net output of the dominant firm falls only in the range of costs which applies to segment III of the post-divestment price function (as defined in Proposition 1). For this range of costs, the divestment affects capacity that the dominant firm was not utilising pre-divestment, and the dominant firm reduces its output due to a reduction in its residual demand. As it is shown in the proof of Proposition 1, the output of the dominant firm falls by $\frac{\delta}{3}$ in this case. This creates a productive inefficiency which can lead to an overall reduction in total welfare, for sufficiently small divestments, as Proposition 2 establishes.

The dominant firm's net output increases for intermediate divestments located other than in the cost range which applies to segment III of the post-divestment price function. As a result, total production costs are necessarily lower post-divestment in these other cases. Note that Proposition 2 also establishes that the optimal divestment from a consumer welfare perspective always increases total welfare as well, compared to the pre-divestment outcome.

4 Virtual Power Plants

In this section of the article we describe the impact of financial contracts (modelled as VPPs) on equilibrium prices, in the same model of a dominant firm facing a competitive fringe considered above for the case of divestments. VPPs are typically structured as call options that are imposed on a producer for a certain part of its generation output. The option holders have a right to acquire electricity from the generator at a strike (or exercise) price p^s, and can re-sell this output in the spot market to obtain the market price p.[11] The option will therefore be exercised whenever $p > p^s$. We assume that both the volumes associated with these options and the strike prices are set exogenously by a regulator for market power mitigation purposes. In what follows we analyse the impact of VPPs from a static perspective, and abstract from some of potential institutional advantages associated with VPPs (as discussed above).

[11] We assume that multiple players hold the options and do not exercise any market power when exercising their options.

For analytical convenience, so as to obtain results which are directly comparable to those derived above in relation to divestments, we assume that the VPP scheme entails the sale of a group of infinitesimally small call options each with a different strike price.[12] The sum of the volumes associated with the aggregate set of options equals δ. The strike prices associated with each option are defined along an increasing and continuous linear function that has the same slope (γ) as the marginal cost function of the dominant firm.[13] The VPP scheme that we model is therefore designed to mimic a physical plant divestment of size δ, from a firm with a linear and increasing marginal cost function with slope γ. As in the case of divestments, the highest strike price associated with a VPP can also be expressed as $\overline{c}$, implying that the lowest strike price is given by $\overline{c} - \gamma\delta$. This allows for a direct comparison of the relative impact of a VPP and of a divestment that have the same position on the cost curve of the dominant firm, as measured by $\overline{c}$. As we show below in Proposition 3, the restriction on the shape of the VPP does not affect the results on the nature of the optimal VPP (i.e. the VPP which leads to the largest reduction in spot prices).[14]

4.1 Prices with VPPs

The following Proposition describes the impact of a VPP on prices, depending on the strike prices associated with the scheme.

Proposition 3 (Virtual Power Plants) *The post-VPP price function depends on the level of the range of strike prices associated with the VPP (as identified by the level of the highest strike price $\overline{c}$). This function ($p^{VPP}(\overline{c})$) has 3 segments, for $\delta \leq \frac{\mu}{2}$:*

Segment	***Price***	***Range of $\overline{c}$***
I^{VPP}	$p^* - \Delta_p$	$\gamma\delta \leq \overline{c} < p^* - \Delta_p$
II^{VPP}	$\frac{1}{2}\left(\frac{\overline{c}}{2} + \gamma\left(\mu - \frac{\delta}{2}\right)\right)$	$p^* - \Delta_p \leq \overline{c} < p^* + 3\Delta_p$
III^{VPP}	p^*	$\overline{c} \geq p^* + 3\Delta_p$

,

$p^{VPP}(\overline{c})$ is weakly increasing in $\overline{c}$. The VPP which achieves the largest price reduction (i.e. the optimal VPP) is achieved by setting $\overline{c} < p^* - \Delta_p$, that is, by choosing a baseload VPP which is exercised in its entirety.

Proof. See Appendix A.3. ■

[12] This set-up is similar to that employed by Willems (2006) to describe the impact of VPPs.

[13] In the case of a VPP that is exercised in its entirety, our set-up implies that the dominant firm receives financial flows $\int_{q'-\delta}^{q'} \gamma x dx$ from the option holders (where $\gamma q'$ equals the highest strike price associated with the VPP), but foregoes market revenues $p\delta$. If the option is not exercised in its entirety, then the dominant firm will receive the following payment from the option holders: $\int_{q'-\delta}^{\mu-q_d} \gamma x dx$, where $\mu - q_d = q_f$, which determines the market price (i.e. $p = \gamma q_f$).

[14] The effectiveness of a VPP is maximised by choosing a set of strike prices that are such that the option is exercised in its entirety. This result is independent of the slope of the strike price function, and can be also achieved with a constant strike price.

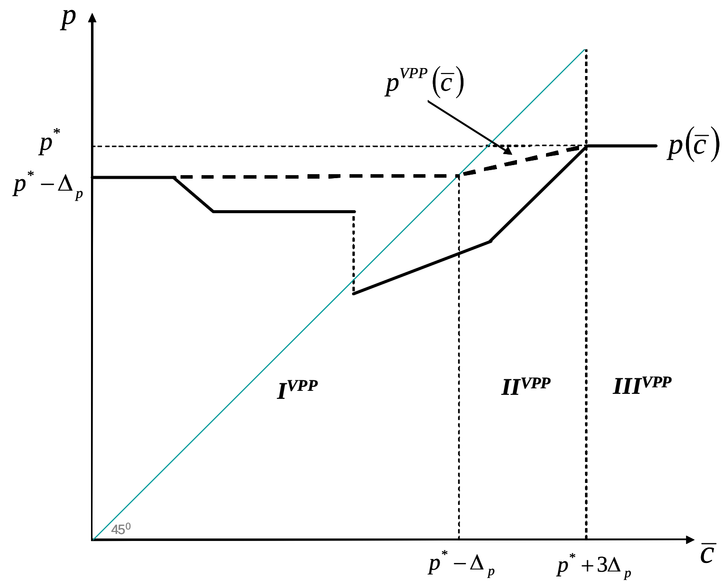

Figure 3: Impact of a VPP on prices (and comparison with a divestment of intermediate size), as a function of the position of the VPP and of the divestment.

The post-VPP price function is shown in Figure 3, as a function of the position of the VPP $\overline{c}$. The figure also plots the post-divestment price function $p(\overline{c})$ for a divestment of the same size (assuming intermediate values of δ, as considered in Proposition 1). As the figure shows the post-VPP price lies below the residual monopoly price p^* for $\overline{c}$ sufficiently low (i.e. $\overline{c} < p^* + 3\Delta_p$), as it is the case for intermediate divestments.

In segment I of the post-VPP price function, all of the call options associated with the VPP are exercised, and the VPP has the same impact as a forward contract of size δ. In this case the market price drops by Δ_p, which is the same price reduction achieved by a baseload divestment (as shown in Proposition 1). The reason why a baseload VPP yields the same price as a baseload divestment of the same size is that it effectively removes an amount δ from the infra-marginal output of the dominant firm, inducing it to price lower. This is equivalent to losing some infra-marginal (i.e. low-cost) output through the divestment of baseload capacity to a competitive fringe, and facing a reduction in residual demand of the same size. Applying contract cover of size δ is effectively equivalent to the displacement of both the cost and residual demand functions of the dominant firm by an amount δ that is caused by a divestment of baseload generation capacity.

The spot price associated with a baseload VPP applies until this price is higher than the highest strike price of the VPP, allowing the VPP to be exercised in its entirety. The impact of a baseload VPP therefore does not depend on the distribution of strike prices, as long as the highest strike price lies below $p^* - \Delta_p$.

In segment II of the post-VPP price function the highest strike price rises above $p^* - \Delta_p$, implying that it is not profitable to exercise some of the call options in the VPP. This in turn results in a higher amount of output for the dominant firm benefitting from spot prices (i.e. a lower level of contract cover), inducing it to set higher level spot prices. The price set in segment II therefore increases with the level of the highest strike price of the VPP, until none of the options are exercised in equilibrium (i.e. until the lowest strike price is above the residual monopoly price). When the latter condition holds, segment III applies and the VPP is ineffective (i.e. the post-VPP spot price is the same as p^*).

4.2 Price comparison between the optimal VPP and the optimal divestment of intermediate size

Proposition 3 establishes that VPP are never more effective than divestments of the same size and same position on the cost curve of the dominant firm, for the intermediate values of $\frac{\delta}{\mu}$ considered in Proposition 1. As noted, divestments and VPPs achieve the same price reduction when they are both baseload.

However, divestments of non-baseload plants can be several-fold more effective in reducing prices than VPPs. In particular, the optimal divestment can be several-fold more effective than the optimal VPP (which is in turn equivalent to a baseload divestment, as shown above).

Corollary 2 below compares the price reduction achieved by the optimal divestment to that obtained by the optimal VPP (the latter being denoted as $\Delta_p \equiv \frac{\gamma\delta}{3}$ in Proposition 1 and in Proposition 3).

Corollary 2 *For divestments of intermediate size, the ratio between the price reduction achieved by the optimal divestment and the optimal VPP is given by* $R\left(\frac{\delta}{\mu}\right) = \frac{p^* - p(\hat{c})}{\Delta_p}$ *which can be expressed as:*

$$R\left(\frac{\delta}{\mu}\right) = \left(2 - \frac{3\sqrt{6}}{4}\right)\frac{\mu}{\delta} + \frac{3\sqrt{6}}{4}$$

This function is decreasing in $\frac{\delta}{\mu}$. *At the lower bound of the relevant range of* $\frac{\delta}{\mu}$ *(i.e.* $\frac{\delta}{\mu} = 1 - \frac{12}{5\sqrt{6}}$*),* $R\left(\frac{\delta}{\mu}\right) \approx 9.9$. *At the upper bound of the relevant range of* $\frac{\delta}{\mu}$ *(i.e.* $\frac{\delta}{\mu} = 1 - \frac{2}{\sqrt{6}}$*),* $R\left(\frac{\delta}{\mu}\right) \approx 2.7$.

Corollary 2 shows that selecting the position of the divestment optimally results in a price reduction that is larger than that achieved with baseload divestment and/or with the optimal VPP. For relatively small divestments (i.e. at the lower end of the range considered in Proposition 1) the price reduction achieved by the optimal divestment is approximately 10 times larger than that which a VPP can yield (for a given demand level). At the higher range of the relative size of the divestment described in Proposition 1, optimal divestments are close to 3-times more effective in reducing prices than a VPP. The $R\left(\frac{\delta}{\mu}\right)$ function for all divestment sizes is illustrated in the next Section of the paper.

Given that the price reduction achieved by a VPP is proportional to δ, this means that the function $R(\frac{\delta}{\mu})$ derived in Corollary 2 also describes the size of the VPP required to match an optimal divestment of size δ, expressed as a ratio of μ. That is, if $R(\frac{\delta}{\mu}) = 5$ (which is the case for

$\frac{\delta}{\mu} \approx \frac{1}{20}$), then in order to achieve the same price reduction as an optimal divestment of size $\delta = \frac{\mu}{20}$, a VPP would need to be 5 times larger, i.e. it would need to equal $\frac{\mu}{4}$.

The reason for the significant difference in effectiveness between divestments and VPPs is that the latter only affect the financial flows received by the dominant firm, but do not affect the production capacity that is available to competitors of the dominant producer. As we have shown, divestments can be targeted at strategic plants which are being withheld by the dominant firm, and which become price-setting in the post-divestment equilibrium. Divesting these plants can significantly enhance the pro-competitive impact of a divestment.

The same cannot be achieved with a VPP scheme, since VPPs do not directly involve generation plants and therefore cannot be tailored to apply to specific types of generation capacity. The effect of a VPP on a dominant producer is to lead to an outwards shift in its marginal revenue function (due to the fact that less of its infra-marginal output receives the spot price, so that a price reduction is less costly for the firm). This leads to an output increase for the dominant firm, along its pre-divestment marginal cost function, and consequently a price reduction. However − unlike a divestment − the VPP cannot make the residual demand faced by the dominant producer flatter, nor can it be targeted at plants which the dominant firm was not utilising in the pre-divestment equilibrium.

A further implication of the comparison between divestments and VPPs is that mimicking the properties of the optimal divestment by setting a range for the strike prices in the VPP that is equal to the cost range of the optimal divestment does not increase the pro-competitive impact of a VPP (relative to a baseload VPP). In particular, for intermediate divestments it can be shown that $\hat{c} < p^* - \Delta_p$, which implies that a VPP that is designed to mimic the optimal divestment (i.e. with a maximum strike price equal to $\hat{c}$) is actually equivalent to a baseload VPP that is always exercised, and is therefore significantly less effective than the optimal divestment.

The reason for this result is that with a VPP the dominant firm receives the strike price rather than the spot price for part of its sales. In situations where the VPP's strike prices span the equilibrium price that can be achieved with the optimal divestment, the dominant firm does not face incentives to reduce the spot price below $\hat{c}$ (which in turn is below $p^* - \Delta_p$) in order to decrease the number of options which are exercised. Doing this would be sub-optimal, since the dominant firm would forego higher revenues from the option holders in exchange for lower revenues from the spot market (with no additional increase in its sales relative to the pre-divestment equilibrium). In the case of divestments, lowering the spot price to a level below $\hat{c}$ is instead optimal for the dominant firm, since it reduces the output that is produced by the divested assets, allowing it to increase its sales.

Note finally that dividing the $R\left(\frac{\delta}{\mu}\right)$ function by 2 also measures the relative impact of optimal price-setting entry and baseload entry, as described in Section 3.3. This is because baseload entry yields a price reduction that is twice as large as the one obtained with a baseload divestment.

4.3 Welfare comparison between the optimal VPP and the optimal divestment of intermediate size

The discussion of the welfare effects of divestments presented in Section 3.4 implies that the optimal VPP is welfare-increasing. This follows from the fact that it induces the dominant firm to increase its net output, thus leading to a reduction in the output of high-cost capacity belonging to the competitive fringe. However, the optimal divestment always leads to a greater efficiency increase than the optimal VPP. This result is stated formally in the following Proposition.

Proposition 4 *Optimal divestments of intermediate size increase total welfare by more than the optimal VPP (and/or a baseload divestment) of the same size.*

Proof. See Appendix A.4 ■

This Proposition therefore shows that divestments, if chosen optimally, can increase both consumer and total welfare by more than VPPs. The intuition for the welfare result is that at the optimal divestment more of the production of the competitive fringe shifts from high cost capacity to lower cost capacity (i.e. that which is divested), coupled with the fact that the dominant firm also increases its net output (for $\frac{\delta}{\mu} < 1 - \frac{2}{\sqrt{6}}$). This efficient reallocation of output takes place to a greater extent than with a VPP, since the latter yields a lower reduction in prices.

5 Prices with small and large divestments

This section of the article extends some of the results presented in Section 3 to cases with smaller and larger divestments than those considered in Proposition 1. We show that the core result shown above (i.e. the fact that an optimally chosen divestment can be significantly more effective in reducing prices than a baseload divestment and/or a VPP) extends to the cases of small and large divestments. The optimal divestment becomes as effective as a baseload divestment or a VPP of the same size only when the divestment is so large that it achieves the competitive price independently of its position on the cost curve of the dominant producer. For this to be the case, the divested capacity needs to equal the competitive output level of the dominant producer, which is equivalent to 50% of total demand (i.e. $\frac{\mu}{2}$). This would clearly represent a very large divestment which is not realistic for practical purposes.

The following Proposition summarises the properties of the optimal divestment, and its relationship to a baseload divestment of the same size, for small divestments (as defined in the Proposition).

Proposition 5 (Small divestments) *For the case where $\frac{\delta}{\mu} \in \left[0, 1 - \frac{12}{5\sqrt{6}}\right]$, the optimal divestment is given by setting $\bar{c} = \gamma\left(\frac{2}{3}\mu + \delta - \frac{1}{3}\sqrt{\delta\left(2\mu - \delta\right)}\right)$. The optimal divestment achieves a price of $p^* - \frac{\gamma}{3}\sqrt{\delta\left(2\mu - \delta\right)}$, whilst a baseload divestment yields a price of $p^* - \Delta_p$. For small divestments, we have that $R\left(\frac{\delta}{\mu}\right) = \sqrt{\frac{2\mu}{\delta} - 1}$, which is decreasing in $\frac{\delta}{\mu}$ and takes a value of approximately 9.9 for $\frac{\delta}{\mu} = 1 - \frac{12}{5\sqrt{6}}$.*

Proof. See Appendix A.5. ■

This Proposition shows that for small divestments the optimal divestment remains several-fold more effective than a baseload divestment. As for the case of intermediate divestment, the optimal divestment has a cost range that is below the pre-divestment price[15] and higher than the competitive price. Contrary to the intermediate case, for small divestments the optimal divestment is such that the dominant producer faces the incentive to set a price equal to the lowest cost of the divested capacity (i.e. $p = \bar{c} - \gamma\delta$), which is equivalent to pricing on segment V of the post-divestment price function plotted in Figure 2. This means that the none of the divested units produce in the post-divestment equilibrium (even though they can still be considered price-setting since the cheapest divested unit sets the price). This also means that the dominant producer never prices on the flatter segment of its residual demand curve in this case. The output of the dominant firm increases in the case of the optimal divestment of small size, implying that the divestment is welfare-increasing.

The following Proposition summarises the properties of the optimal divestment, and its relationship to a baseload divestment, for large divestments (as defined in the Proposition).

Proposition 6 (Large divestments) *For the case where* $\frac{\delta}{\mu} \in (1 - \frac{2}{\sqrt{6}}, \frac{1}{2}]$*, setting* $\bar{c} = \gamma\left(\frac{\mu}{3} + \delta\right)$ *achieves the optimal divestment (even though the optimal divestment is not unique). The optimal divestment always yields the competitive price* $p^c = \frac{\gamma\mu}{2}$*, whilst a baseload divestment yields a price of* $p^* - \Delta_p > p^c$ *for* $\frac{\delta}{\mu} < \frac{1}{2}$*. For large divestments, we have that* $R\left(\frac{\delta}{\mu}\right) = \frac{1}{2}\frac{\mu}{\delta}$*, which is decreasing in* $\frac{\delta}{\mu}$ *and implies* $R\left(\frac{\delta}{\mu}\right) = 1$ *for* $\frac{\delta}{\mu} = \frac{1}{2}$*.*

Proof. See Appendix A.6. ■

Proposition 6 shows that the optimal divestment for sufficiently large divestment always achieves the competitive price, thereby maximising both consumer and total welfare. The divested units in this case are price-setting post-divestment, and their marginal costs encompass the post-divestment price (as in the case of intermediate divestments). The optimal divestment can be achieved by setting $\bar{c} = \gamma\left(\frac{\mu}{3} + \delta\right)$, which is equivalent to divesting the lowest-cost capacity of aggregate size δ that is withheld by the dominant firm in the pre-divestment equilibrium (whilst for the cases of small and intermediate divestments relatively more expensive capacity needs to be divested). Contrary to the other cases, the optimal divestment is not unique for large divestments. Also in this case, baseload divestments are always less effective than optimally-chosen large divestment, unless the size of the divestment is very large (i.e. it equals half of total demand, which is equivalent to the competitive output of the dominant producer).

Using the Propositions for small, intermediate and large divestments respectively, we can construct the function describing the ratio of the price impact of the optimal divestment and of a baseload divestment (or a baseload VPP of the same size) for all values of δ between 0 and $\frac{\mu}{2}$.

[15] This follows from the fact that $\gamma\left(\frac{2}{3}\mu + \delta - \frac{1}{3}\sqrt{\delta(2\mu - \delta)}\right) < \frac{2}{3}\gamma\mu$ for $\frac{\delta}{\mu} < \frac{1}{5}$ which is satisfied in the case of small divestments.

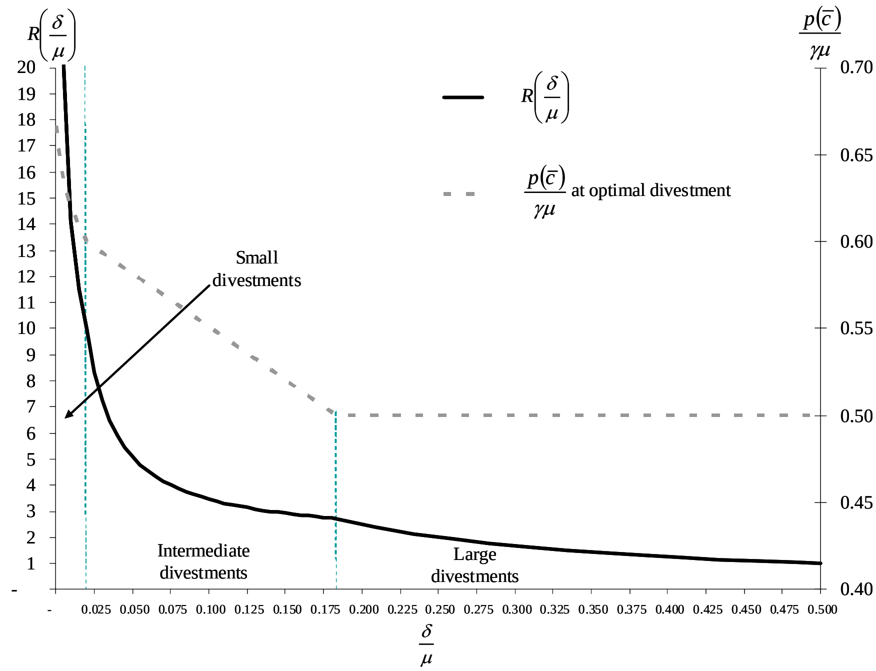

Figure 4: Ratio between the reduction in prices achieved by the optimal divestment and a baseload divestment (or a baseload VPP); and the post-divestment price at the optimal divestment (normalised by $\gamma\mu$).

This is shown in Figure 4. This function decreases monotonically with $\frac{\delta}{\mu}$ and converges to 1 as the divestment becomes very large. Figure 4 also shows the post-divestment price associated with the optimal divestment for each value of $\frac{\delta}{\mu}$ (normalised by $\gamma\mu$).[16] This function also decreases monotonically with the size of the divestment, and it reaches the competitive price (i.e. $\frac{p(\bar{c})}{\gamma\mu} = 0.5$) for $\frac{\delta}{\mu} \geq 1 - \frac{2}{\sqrt{6}} \approx 0.18$.

6 Conclusion

This paper has studied the impact of remedy design in a model where a dominant producer faces a competitive fringe with the same cost structure. We analysed the effect on market prices of transfers of capacity from a dominant producer to a competitive fringe. We show that divesting capacity that is marginal (or price-setting) in the post-divestment equilibrium can be several fold more

[16] Using the results given above, this function is as follows:

$$\frac{p(\bar{c})}{\gamma\mu} = \begin{cases} \frac{1}{3}\left(2 - \sqrt{\frac{\delta}{\mu}\left(2 - \frac{\delta}{\mu}\right)}\right) & if \quad \frac{\delta}{\mu} \in \left[0, 1 - \frac{12}{5\sqrt{6}}\right] \\ \frac{\sqrt{6}}{4}\left(1 - \frac{\delta}{\mu}\right) & if \quad \frac{\delta}{\mu} \in \left(1 - \frac{12}{5\sqrt{6}}, 1 - \frac{2}{\sqrt{6}}\right] \\ \frac{1}{2} & if \quad \frac{\delta}{\mu} \in \left(1 - \frac{2}{\sqrt{6}}, \frac{1}{2}\right] \end{cases}.$$

effective in reducing prices that an equivalent release of baseload capacity. In order to maximise the effectiveness of the divestment from a consumer welfare perspective, the divested capacity needs to include assets which are sufficiently competitive to impose a competitive constraint on the dominant firm but whose costs are not too low so as to induce the dominant producer to accept a larger loss in its output and keep prices high. In the optimal post-divestment equilibrium (for intermediate and large divestments), the cost range of the divested capacity needs to span the post-divestment price (implying that some but not all of the divested capacity produces in equilibrium). The optimal divestment from the perspective of consumer welfare is always efficiency-increasing in our set-up.

We have also compared the effectiveness of divestments to that of VPP schemes. We established that the effectiveness of VPPs is maximised when all of the options which are sold are exercised. This is achieved by setting a sufficiently low exercise price. In this case, the VPP reduces prices as much as a divestment of baseload generation of the same size. Given that the optimal divestment is several-fold more effective than a baseload divestment, our findings also imply that divestments can be significantly more pro-competitive than VPPs (if the divested plants are selected optimally). Whilst VPPs may be preferred to a divestment because of other reasons (e.g. ease of implementation, and reversibility), our results show that relying on VPPs as a remedy rather than divestment can lead to a significant reduction in the effectiveness of the intervention from a market power mitigation perspective.

Our findings have a direct policy relevance, given that divestments and VPPs are frequently accepted by competition authorities as remedies in antitrust cases relating to the electricity sector. Our results are also relevant to the evaluation of merger effects in power generation markets, since divestments are the exact opposite of a merger. The findings of this paper imply that a merger where a portfolio generator buys price-setting capacity from a smaller competitor can have significantly greater effect on prices than one where additional baseload capacity is purchased instead. This can be interpreted as meaning that the competitive constraint exercised by price-setting capacity is much greater than that imposed by baseload generation. By the same token, our results indicate that the price-increasing effect of the acquisition of a given volume of baseload generation by a firm with market power can be remedied by significantly smaller divestments of price-setting capacity. Finally, our results also imply that the entry of price-setting independent capacity can constrain prices significantly more than the entry of low-cost plants.

Possible extensions of the work presented in this paper include the analysis of cases with variable demand levels (which is directly relevant to electricity markets), and with oligopoly interaction. Obtaining analytical results for the case of oligopoly interaction may be a challenge in our set-up, given the cost discontinuities created by the divestments of generation capacity. We expect however that the intuitions developed in this paper would also extend to standard oligopoly cases (e.g. Cournot or Supply Function Equilibria).

Finally, whilst the set-up employed in this paper is developed with the electricity generation market in mind, our results also extend to other industries with homogenous products and increasing cost functions (e.g. mining).

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A Appendix

A.1 Proof of Proposition 1

This Proposition relates to the case where $\frac{\delta}{\mu} \in \left(1 - \frac{12}{5\sqrt{6}}, 1 - \frac{2}{\sqrt{6}}\right]$. The dominant firm's post-divestment marginal cost is defined by the following two-step function:

$$c_d = \begin{cases} \gamma q_d & if \quad q_d < q' - \delta \\ \gamma(q_d + \delta) & if \quad q_d \geq q' - \delta \end{cases},$$

while the competitive fringe's post-divestment marginal cost function is defined by the following three-step function:

$$c_f = \begin{cases} \gamma(\mu - q_d - \delta) & if \quad q_d < \mu - q' - \delta \\ \frac{\gamma}{2}(\mu + q' - q_d - \delta) & if \quad \mu - q' - \delta \leq q_d \leq \mu - q' + \delta \\ \gamma(\mu - q_d) & if \quad q_d > \mu - q' + \delta \end{cases}.$$

As the model is discontinuous we have to study the firm's maximization problem in each of the regions defined by q' (and δ). The proof proceeds in two steps. First, we will derive the necessary and feasibility conditions for the equilibrium existence in each of these regions. A unique candidate equilibrium can exist inside each region since the model is linear. Second, we will study the existence of profitable deviations at each candidate equilibrium and equilibria at the regions where the feasibility conditions are not satisfied.

Necessary and feasibility conditions for interior equilibria

Case I **(baseload divestment)**: in this region the dominant firm and the competitive fringe of firms produce, respectively, at a higher and lower marginal cost than in the pre-divestment case, i.e., $c_d = \gamma(q_d + \delta)$ and $c_f = \gamma(\mu - q_d - \delta)$. The dominant firm maximises $\pi_d^I = p^I q_d^I - \frac{\gamma}{2}(q_d^I)^2 - \gamma\delta q_d^I$ with respect to q_d^I and subject to $p^I = c_f$, which yields $q_d^I = q_d^* - \frac{2}{3}\delta$, implying that $p^I = p^* - \frac{\gamma\delta}{3}$. The feasibility conditions are $q_d^I < \mu - q' - \delta$ and $q_d^I > q' - \delta$, thus $q' < \frac{1}{3}\min\{2\mu - \delta, \mu + \delta\}$. Since $\delta < \frac{\mu}{2}$ this condition reduces to: $q' < \frac{\mu+\delta}{3}$.

Case III: the dominant firm produces at the pre-divestment marginal cost, while the competitive fringe produces at a lower marginal cost, i.e., $c_d = \gamma q_d$ and $c_f = \gamma(\mu - q_d - \delta)$. Thus, $p^{III} = \gamma(\mu - q_d - \delta)$ and $\pi_d^{III} = p^{III} q_d^{III} - \frac{\gamma}{2}(q_d^{III})^2$. The first-order condition yields $q_d^{III} = q_d^* - \frac{\delta}{3}$, implying that $p^{III} = p^* - \frac{2\gamma\delta}{3}$. The feasibility conditions are $q_d^{III} < \mu - q' - \delta$ and $q_d^{III} \leq q' - \delta$, which for $\delta < \frac{\mu}{4}$ (which is the case for the range of δ that we consider) boil down to: $\frac{\mu+2\delta}{3} \leq q' < \frac{2(\mu-\delta)}{3}$. Conversely, if $\delta \geq \frac{\mu}{4}$, no equilibrium exists in the region of Case III.

Case IV: the dominant firm produces at the pre-divestment marginal cost, while the competitive fringe produces at the flatter part of its marginal cost function, i.e., $c_d = \gamma q_d$ and $c_f = \frac{\gamma}{2}(\mu + q' - q_d - \delta)$. Thus, $p^{IV} = \frac{\gamma}{2}(\mu + q' - q_d - \delta)$ and $\pi_d^{IV} = p^{IV} q_d^{IV} - \frac{\gamma}{2}(q_d^{IV})^2$. From the first-order condition we obtain $q_d^{IV} = \frac{\mu+q'-\delta}{4}$, so $p^{IV} = \frac{3}{8}(\gamma(\mu - \delta) + \overline{c})$. The feasibility condition $\mu - q' - \delta \leq q_d^{IV} \leq \mu - q' + \delta$ can be rewritten as $(3/5)(\mu - \delta) \leq q' \leq (3/5)\mu + \delta$, and the feasibility condition $q_d^{IV} \leq q' - \delta$ can be rewritten as $q' \geq \delta + \mu/3$.

Notice that $\frac{3}{5}(\mu-\delta) \geq \delta + \frac{\mu}{3}$ if $\delta \leq \frac{\mu}{6}$. In such a case the feasibility conditions boil down to: $\frac{3}{5}(\mu-\delta) \leq q' \leq \frac{3}{5}\mu + \delta$.

Conversely, if $\delta > \frac{\mu}{6}$, the feasibility conditions reduce to: $\delta + \frac{\mu}{3} \leq q' \leq \frac{3}{5}\mu + \delta$.

Case VI: the dominant firm and the competitive fringe of firms produce at the pre-divestment marginal cost, i.e., $c_i = \gamma q_i$ for $i = d, f$. Thus, the first-order condition yields the same result as in the pre-divestment case: $q_d^{VI} = q_d^*$ and $p^{VI} = p^*$. Here, the feasibility conditions are $q_d^{VI} > \mu - q' + \delta$ or, equivalently, $q' > \frac{2}{3}\mu + \delta$, and $q_d^{VI} \leq q' - \delta$, or, equivalently, $q' \geq \frac{\mu}{3} + \delta$. Thus, we have that: $q' > \frac{2}{3}\mu + \delta$.

Infeasible cases or sub-optimal cases

Case i: $c_d = \gamma(q_d + \delta)$ and $c_f = \frac{\gamma}{2}(\mu + q' - q_d - \delta)$. The first-order condition yields $q_d = \frac{1}{4}(\mu + q' - 3\delta)$. The feasibility condition $\mu - q' - \delta \leq q_d \leq \mu - q' + \delta$ implies that $\frac{3\mu-\delta}{5} \leq q' \leq \frac{3\mu+7\delta}{5}$, while the feasibility condition $q_d > q' - \delta$ implies that $q' < \frac{\mu+\delta}{3}$. Since $\frac{\mu+\delta}{3} < \frac{3\mu+7\delta}{5}$, the two conditions reduce to $\frac{3\mu-\delta}{5} \leq q' < \frac{\mu+\delta}{3}$. However $\frac{\mu+\delta}{3} > \frac{3\mu-\delta}{5}$ holds only if $\delta > \frac{\mu}{2}$.

Case ii: $c_d = \gamma(q_d + \delta)$ and $c_f = \gamma(\mu - q_d)$. From the first-order condition we have $q_d = \frac{\mu-\delta}{3}$. The condition $q_d > \mu - q' + \delta$ can be rewritten as $q' > \frac{2}{3}(\mu + 2\delta)$, while $q_d > q' - \delta$ can be rewritten as $q' < \frac{\mu+2\delta}{3}$. Therefore, we have that $\frac{2}{3}(\mu + 2\delta) < q' < \frac{\mu+2\delta}{3}$, which is a contradiction.

Case iii: the post-divestment marginal cost curve passes through the second jump of the marginal revenue curve. If so, the higher value of the marginal revenue function at $q_d = \mu - q' + \delta$, i.e., $\frac{\gamma}{2}(\mu + q' - \delta) - \gamma(\mu - q' + \delta)$, must be higher than the corresponding marginal cost: $\gamma(\mu - q' + \delta + \delta)$. This requires that $q' > \frac{3\mu+7\delta}{5}$. Also, the lower value of the marginal revenue function at $q_d = \mu - q' + \delta$, i.e., $\gamma(\mu - 2(\mu - q' + \delta))$, must be lower than marginal cost: $\gamma(\mu - q' + \delta + \delta)$. This requires that $\frac{2\mu+4\delta}{3} > q'$. Thus, $\frac{3\mu+7\delta}{5} < q' < \frac{2}{3}(\mu + 2\delta)$, which holds since $\delta < \mu$. In addition, we need that $q' - \delta < \mu - q' + \delta$, i.e. $q' < \frac{\mu}{2} + \delta$. Nevertheless, $\frac{\mu}{2} + \delta < \frac{3\mu+7\delta}{5}$ holds, which is a contradiction.

Case iv: the third segment of the marginal revenue curve passes through the jump of the marginal cost curve. This requires that $\gamma((q' - \delta) + \delta) > \gamma(\mu - 2(q' - \delta))$, i.e., $q' > \frac{\mu+2\delta}{3}$, and that $\gamma(\mu - 2(q' - \delta)) > \gamma(q' - \delta)$, i.e. $q' < \frac{\mu}{3} + \delta$. Both conditions can be rewritten as $\frac{\mu+2\delta}{3} < q' < \frac{\mu}{3} + \delta$. In addition, we need that $q' - \delta > \mu - q' + \delta$, or, equivalently, if $q' > \frac{\mu}{2} + \delta$. However, $\frac{\mu}{3} + \delta < \frac{\mu}{2} + \delta$ holds.

Case v: The flat part of the marginal revenue curve passes through the jump of the marginal cost curve. If so, the flat part of the marginal revenue curve at $q_d = q' - \delta$, i.e., $\frac{\gamma}{2}(\mu + q' - \delta) - \gamma(q' - \delta)$, must be lower than the post-divestment marginal cost: $\gamma(q_d + \delta) = \gamma q'$. This requires that $q' > \frac{\mu+\delta}{3}$. Also, the marginal revenue curve at $q_d = q' - \delta$ must be higher than the pre-divestment marginal cost: $\gamma(q' - \delta)$. This requires that $q' < \frac{\mu}{3} + \delta$. In addition, we need that $\mu - q' + \delta < q' - \delta < \mu - q' + \delta$, or, equivalently, $\frac{\mu}{2} < q' < \frac{\mu}{2} + \delta$. These four conditions can be rewritten as: $\max\{\frac{\mu}{2}, \frac{\mu+\delta}{3}\} < q' \leq \min\left\{\frac{\mu}{2} + \delta, \frac{\mu}{3} + \delta\right\}$ or $\frac{\mu}{2} < q' \leq \frac{\mu}{3} + \delta$ provided that $\delta < \frac{\mu}{2}$. Note that $\frac{\mu}{3} + \delta > \frac{\mu}{2}$ if and only if $\delta > \frac{\mu}{6}$. Note also that for $\delta < \frac{\mu}{5}$ (which holds in this Proposition), the range of q' where case v holds is always contained within the range of Case III (i.e. $\frac{\mu}{2} > \frac{\mu+2\delta}{3}$ and $\frac{2}{3}(\mu - \delta) > \delta + \frac{\mu}{3}$). As we show below, for $\delta \leq \left(1 - \frac{2}{\sqrt{6}}\right)\mu$ then Case III yields a greater level for profits for the dominant firm than Case IV as long as $q' < \left(\frac{2\sqrt{6}}{3} - 1\right)(\mu - \delta)$. The condition $\delta \leq \left(1 - \frac{2}{\sqrt{6}}\right)\mu$

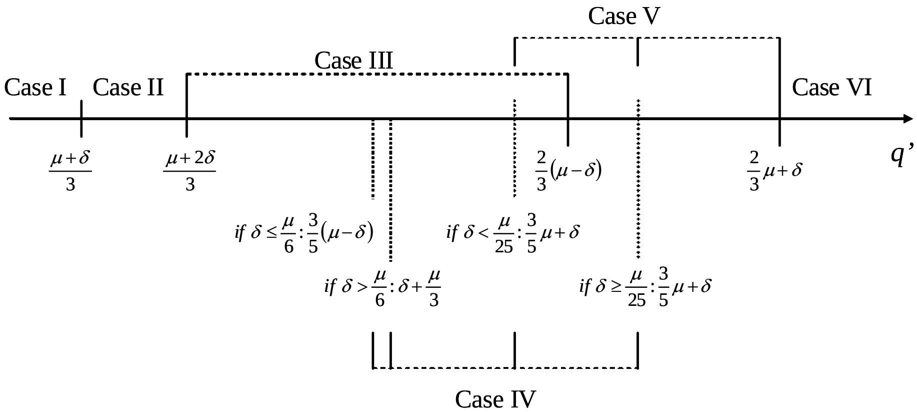

Figure 5: Equilibrium cases for intermediate divestments.

implies that $\left(\frac{2\sqrt{6}}{3}-1\right)(\mu-\delta) > \frac{\mu}{3}+\delta$ implying that for $\frac{\mu}{2} < q' < \frac{\mu}{3}+\delta$ Case III is always more profitable than Case IV. Given that case v is a constrained version of Case IV (since revenues are determined on the same segment of the residual demand curve, but total costs are constrained to be set by the position of the jump in the marginal cost function, and cannot be optimally set along the pre-divestment cost function as in case IV), this implies that Case III also yields larger profits than case v, which cannot be an equilibrium.

Profitable deviations and equilibria

Based on the conditions set out above, the following equilibrium cases can be identified (these are illustrated in Figure 5 in this proof):

Case I: $q' < \frac{\mu+\delta}{3}$. Here, the candidate equilibrium, q_d^I, is the unique equilibrium. The marginal revenue is higher than the marginal cost for $q_d < q_d^I$, so decreasing the output is no profitable. Conversely, the marginal cost is always higher than the marginal revenue for any $q_d > q_d^I$: the marginal revenue curve, which is decreasing in q_d, jumps up at $\mu - q' - \delta$, however it does not intersect with the marginal cost curve provided that $\delta < \frac{\mu}{2}$ (see infeasible Case i). Finally, the marginal revenue curve jumps down at $\mu - q' + \delta$.

Case II: $\frac{\mu+\delta}{3} \leq q' < \frac{\mu+2\delta}{3}$. Here, Cases I, III, IV and VI are not feasible. Notice that $q'-\delta < \mu - q' - \delta \Leftrightarrow q' < \frac{\mu}{2}$, moreover $\frac{\mu+2\delta}{3} < \frac{\mu}{2} \Leftrightarrow \delta < \frac{\mu}{4}$. Therefore, if $\delta < \frac{\mu}{4}$ holds and q' is inside of the region of Case II, we have that the first step of the marginal revenue curve passes through the jump of the marginal cost curve. The dominant firm does not have incentive to produce more than $q'-\delta$ (the marginal cost is higher than the marginal revenue for any $q_d > q'-\delta$ since Case i is not feasible), and it does not have incentive to produce less than $q'-\delta$ (the marginal cost is lower than the marginal revenue). Thus, in this region the dominant firm finds it optimal to set $q_d^{II} = q'-\delta$. From $p = c_f = \gamma(\mu - q_d - \delta)$, we have that $p^{II} = \gamma(\mu - q')$.

Case III: $\frac{\mu+2\delta}{3} \leq q' < \frac{2}{3}(\mu-\delta)$, **and Case** IV: $\frac{3}{5}(\mu-\delta) \leq q' \leq \frac{3}{5}\mu+\delta$ (if $\delta \leq \frac{\mu}{6}$), or $\delta + \frac{\mu}{3} \leq q' \leq \frac{3}{5}\mu + \delta$ (if $\delta > \frac{\mu}{6}$). Notice that $\frac{3}{5}(\mu-\delta) < \frac{2}{3}(\mu-\delta)$, i.e., the regions always overlap for $\delta \leq \frac{\mu}{6}$. Moreover, for $\delta < \frac{\mu}{5}$ the regions also overlap (since $\delta + \frac{\mu}{3} < \frac{2}{3}(\mu - \delta)$). We can therefore have the following cases (within the range of δ considered in this Proposition):

* If $\delta \leq \frac{\mu}{6}$ and $\frac{\mu+2\delta}{3} < q' < \frac{3}{5}(\mu - \delta)$, only Case III occurs, implying that q_d^{III} is the unique equilibrium: the marginal revenue is higher than the marginal cost for any $q_d < q_d^{III}$, while the marginal cost is higher than the marginal revenue for any $q_d > q_d^{III}$: at $q_d = \mu - q' - \delta$ the marginal revenue curve jumps up, but it does not intersect with the pre-divestment marginal cost (this would require that $q' \geq \frac{3}{5}(\mu - \delta)$), and it does not with the post-divestment marginal cost curve either since $\delta < \frac{\mu}{2}$ (see infeasible Case i).

* If $\delta \leq \frac{\mu}{6}$ and $\frac{\mu+2\delta}{3} < q' < \delta + \frac{\mu}{3}$, only Case III occurs and represents the unique equilibrium (see above).

* If the previous conditions on q' do not hold and $q' < \min\{\frac{2}{3}(\mu - \delta), \frac{3}{5}\mu + \delta\}$, then the Cases III and IV can feasibly occur at the same time. In this case the dominant firm will choose the equilibrium with the highest profits, i.e. Case III will represent the equilibrium outcome if $\pi_d^{III} > \pi_d^{IV}$, and Case IV will represent the equilibrium otherwise. From the expressions given above note that π_d^{III} does not depend on the value of q' whilst π_d^{IV} is increasing in q' (as we show formally below). We can therefore identify an indifference value for q' (defined as $\hat{q}$) such that, for $q' < \hat{q}$ we have $\pi_d^{III} > \pi_d^{IV}$ (i.e. Case III represents the equilibrium outcome), and for $q' > \hat{q}$ Case IV is the equilibrium. $\hat{q}$ is given by setting $\pi_d^{III} = \pi_d^{IV}$. From the equilibrium prices and quantities given above, π_d^{III} can be expressed as follows:

$$\pi_d^{III} = p_d^{III} q_d^{III} - \frac{\gamma}{2}\left(q_d^{III}\right)^2 = \frac{2}{9}\gamma\,(\mu - \delta)^2 - \frac{\gamma}{18}\,(\mu - \delta)^2 = \frac{\gamma}{6}\,(\mu - \delta)^2 .$$

To compute π_d^{IV} recall that in Case IV, the equilibrium price can be expressed as $p_d^{IV} = \frac{\gamma}{2}\,(\mu - \delta + q' - q)$. This implies that π_d^{IV} can be expressed as follows:

$$\pi_d^{IV} = p_d^{IV} q_d^{IV} - \frac{\gamma}{2}\left(q_d^{IV}\right)^2 = \frac{\gamma}{2}\left(\mu - \delta + q'\right) q_d^{IV} - \gamma\left(q_d^{IV}\right)^2 = \frac{\gamma}{16}\left(\mu - \delta + q'\right)^2 .$$

The indifference point $\hat{q}$ is therefore given by the following quadratic condition (obtained by simplifying the two expression for profits given above):

$$\begin{aligned} \frac{(\mu - \delta)^2}{3} &= \frac{(\mu - \delta + q')^2}{8} \\ 3\left(q'\right)^2 + 6\,(\mu - \delta)\,q' - 5\,(\mu - \delta)^2 &= 0. \end{aligned}$$

This yields a unique positive root in q' given by:

$$q' = \frac{-6\,(\mu - \delta) + \sqrt{36(\mu - \delta)^2 + 60(\mu - \delta)^2}}{6} = \left(\frac{2\sqrt{6}}{3} - 1\right)(\mu - \delta) \approx 0.63\,(\mu - \delta) .$$

We therefore define $\hat{q} \equiv \left(\frac{2\sqrt{6}}{3} - 1\right)(\mu - \delta)$. As we discuss in the main text, this identifies the optimal divestment policy for the range of δ considered in this Proposition. Note that $\overline{c}(\hat{q}) = \gamma\hat{q}$ is below p^*, as should be expected.

Note that for $q' = \hat{q}$ to be consistent with Case IV it needs to be contained within the range of q' that defines Case IV. This implies the following conditions on δ:

$$\begin{aligned}
\hat{q} &< \frac{3}{5}\mu + \delta \Rightarrow \delta > \left(1 - \frac{12}{5\sqrt{6}}\right)\mu \approx \frac{1}{50}\mu, \\
\text{for } \delta &\leq \frac{\mu}{6}\text{: } \hat{q} \geq \frac{3}{5}(\mu - \delta) \text{ which is always satisfied,} \\
\text{for } \delta &> \frac{\mu}{6} : \hat{q} \geq \frac{\mu}{3} + \delta \Rightarrow \delta \leq \left(1 - \frac{2}{\sqrt{6}}\right)\mu.
\end{aligned}$$

The two resulting conditions on δ are assumed to hold in this Proposition, and to define the range of intermediate divestments.

* If $\frac{3}{5}\mu + \delta < \frac{2}{3}(\mu - \delta)$ (i.e., $\delta < \frac{\mu}{25}$) and $\frac{3}{5}\mu + \delta < q' < \frac{2}{3}(\mu - \delta)$, then the Cases III and V (see below) occur at the same time. If this is the case, and if $\hat{q} < \frac{3}{5}\mu + \delta$ (which requires $\delta > \left(1 - \frac{12}{5\sqrt{6}}\right)\mu$), then in the Case IV the maximum profit is achieved at $q' = \frac{3}{5}\mu + \delta$ (since π_d^{IV} increases with q'), and $\pi_d^{III} > \pi_d^{IV}$ for $q' < \hat{q}$. In the Case V the maximum profit is achieved at $q' = \frac{2}{3}\mu + \delta$ since π_d^V increases with q' (because higher values of q' imply higher levels of the residual demand curve on which the dominant firm is pricing). Therefore, $\pi_d^V(q') > \pi_d^V(\frac{3}{5}\mu + \delta)$ for any $q' \in (\frac{3}{5}\mu + \delta, \frac{2}{3}\mu + \delta)$. Moreover, $\pi_d^V(\frac{3}{5}\mu + \delta) = \pi_d^{IV}(\frac{3}{5}\mu + \delta) > \pi_d^{III} = \frac{\gamma}{6}(\mu - \delta)^2$. Thus, for values of q' higher than $\frac{3}{5}\mu + \delta$, the Case V defines the equilibrium outcome rather than Case III (which is also feasible).

* If $\frac{3}{5}\mu + \delta \geq \frac{2}{3}(\mu - \delta)$ (i.e., $\delta \geq \frac{\mu}{25}$) and $\frac{2}{3}(\mu - \delta) < q' < \frac{3}{5}\mu + \delta$, then only Case IV occurs, implying that q_d^{IV} is the unique equilibrium: the marginal revenue is higher than the marginal cost for any $q_d < q_d^{IV}$, while the marginal cost is higher than the marginal revenue for any $q_d > q_d^{IV}$.

Case V: the pre-divestment marginal cost curve passes through the second jump of the marginal revenue curve. If so, the flat part of the marginal revenue curve at $q_d = \mu - q' + \delta$, i.e., $\frac{\gamma}{2}(\mu + q' - \delta) - \gamma(\mu - q' + \delta)$, must be higher than the marginal cost: $\gamma(\mu - q' + \delta)$. This requires that $q' > \frac{3}{5}\mu + \delta$. Also, the third step of the marginal revenue curve at $q_d = \mu - q' + \delta$, i.e., $\gamma(\mu - 2(\mu - q' + \delta))$, must be lower than the marginal cost: $\gamma(\mu - q' + \delta)$. This requires that $\frac{2}{3}\mu + \delta > q'$. Therefore, we have that $\frac{3}{5}\mu + \delta < q' < \frac{2}{3}\mu + \delta$. The dominant firm will not find it profitable to produce more/less than $q' - \delta$, thus $q_d^V = \mu - q' + \delta$. From $p = c_f = \gamma(\mu - q_d)$, we have that $p^V = \gamma(q' - \delta) = \overline{c} - \gamma\delta$.

Case VI: $q' > \frac{2}{3}\mu + \delta$, here, q_d^{VI} is the unique equilibrium: the marginal revenue is higher than the marginal cost for any $q_d < q_d^{VI}$, while the marginal cost is higher than the marginal revenue for any $q_d > q_d^{VI}$. Recall that it is not feasible that the third step of the marginal revenue curve passes through the jump of the marginal cost curve (see infeasible Case iv).

Optimal divestment

Notice that the minimum p^{II} is achieved at $q' = \frac{\mu + 2\delta}{3}$, where $p^{II} = p^* - \frac{2}{3}\gamma\delta$. Therefore, for a given δ, we have that $p^{III} = \min p^{II} < p^{II} < p^I = p^* - \Delta_p < p^{VI} = p^*$. The minimum p^V is achieved at $q' = \frac{3}{5}\mu + \delta$, where $p^V = \frac{3}{5}\gamma\mu$. The price corresponding to Case IV equals the minimum p^V for $q' = \frac{3}{5}\mu + \delta$, and takes a lower value for $q' < \frac{3}{5}\mu + \delta$ (since it is decreasing in q').

Note also that the price set by the dominant firm at the indifference point between Cases III and IV is necessarily lower in Case IV than in Case III since when the firm deviates to Case IV it prices on the flattest part of its residual demand curve, and it stops pricing on the segment of the residual demand curve obtained when the fringe produces at lower cost. In order to do so it must expand output. Since $p^{III} = \min p^{II} < p^{II} < p^{I}$, and p^{IV} and p^{V} are increasing in $\bar{c}$, it follows that the lowest price is achieved when the divestment is located at $\bar{c} = \gamma\hat{q} \equiv \gamma\left(\frac{2\sqrt{6}}{3} - 1\right)(\mu - \delta)$, i.e. the indifference point between Case III and Case IV. The price at this point is as follows: $p(\hat{c}) = \frac{\sqrt{6}}{4}\frac{\mu-\delta}{\gamma}$.

A.2 Proof of Proposition 2

As it is established in Section 3.4, a sufficient condition for divestments to be welfare-increasing is that the output of the dominant firm (net of the divested capacity) does not decrease. For this to be the case, the marginal cost of the dominant firm in the post-divestment equilibrium must be higher than its marginal cost pre-divestment. This condition can be expressed as follows:

$$\gamma\frac{\mu}{3} \leq c_d = \begin{cases} \gamma q_d & if \quad q_d < q' - \delta \\ \gamma(q_d + \delta) & if \quad q_d \geq q' - \delta \end{cases}.$$

Note that in Cases I and II of the post-divestment equilibrium, we have that $q_d \geq q' - \delta$. A sufficient condition for divestments to increase welfare in those two cases is therefore that $q_d \geq \frac{\mu}{3} - \delta$.

- From the proof of Proposition 1 we have that $q_d^I = \frac{\mu}{3} - \frac{2}{3}\delta$, which satisfies this condition.
- We also have that $q_d^{II} = q' - \delta$. The minimum output in Case II is therefore given when q' is minimised within the range of Case II. This is so for $q' = \frac{\mu+\delta}{3}$, which implies $q_d^{II} = \frac{\mu}{3} - \frac{2}{3}\delta$, which also satisfies the condition.

For other cases, we require $q_d \geq \frac{\mu}{3}$ for welfare to increase. Taking the remaining four cases in turn:

- In Case III, we have that $q_d^{III} = \frac{\mu}{3} - \frac{\delta}{3}$, which does not satisfy the condition.
- In Case IV, we have that $q_d^{IV} = \frac{\mu-\delta}{4} + \frac{q'}{4}$. Output is increasing in q', and is therefore minimised for the lowest q' within the range of Case IV. The lowest q' within Case IV is given by $\left(\frac{2\sqrt{6}}{3} - 1\right)(\mu - \delta)$, which is the location of the optimal divestment. Solving for the corresponding output level yields $q_d^{IV} = \frac{\mu-\delta}{\sqrt{6}}$, which is decreasing in δ. Solving for the maximum feasible δ in the range of intermediate divestment (i.e. $\delta = 1 - \frac{2}{\sqrt{6}}$), we obtain that $q_d^{IV} = \frac{\mu}{3}$, which satisfies the condition for welfare to increase.
- In Case V, we have that $q_d^V = \mu - q' + \delta$, which is decreasing in q'. The maximum q' yields the pre-divestment price in this case and no output change by the fringe. This implies $q_d^V = \frac{\mu}{3}$, which satisfies the condition.

- The condition is trivially satisfied in Case VI, where the divestment has no impact on market outcomes.

The only case where divestments can lead to a reduction in welfare is therefore Case III. In this case, the change in welfare is given by the following expression (recalling that $p^{II} = p^* - \frac{2}{3}\delta$):

$$\Delta W^{III} = \int_{\frac{2}{3}\mu - \frac{2}{3}\delta}^{\frac{2}{3}\mu} \gamma x dx + \int_{\frac{\mu}{3} - \frac{\delta}{3}}^{\frac{\mu}{3}} \gamma x dx - \int_{q' - \delta}^{q'} \gamma x dx.$$

This simplifies to the following: $\Delta W^{III} = \gamma\delta\left(\frac{2}{9}\delta + \frac{5}{9}\mu - q'\right)$, which is decreasing in q'. Substituting for the highest value of q' that is feasible in Case III (i.e. $q' = \left(\frac{2\sqrt{6}}{3} - 1\right)(\mu - \delta)$) , yields the following condition for $\Delta W^{III} \geq 0$:

$$\frac{\delta}{\mu} \geq \frac{6\sqrt{6} - 14}{6\sqrt{6} - 7} \approx 0.09,$$

which is within the range of $\frac{\delta}{\mu}$ considered in the case of intermediate divestments. This proves that for $\frac{\delta}{\mu} < \frac{6\sqrt{6}-14}{6\sqrt{6}-7}$ – and q' high enough – divestments can reduce welfare.

A.3 Proof of Proposition 3

Case I (the option is always exercised)

The profit of the dominant firm is $\pi_d = pq_d - \frac{\gamma}{2}(q_d)^2 + \int_{q'-\delta}^{q'} \gamma x dx - p\delta$ where $p = \gamma(\mu - q_d)$. Simplifying, we obtain

$$\pi_d = pq_d - \frac{\gamma}{2}(q_d)^2 + \frac{\gamma}{2}(-\delta^2 + 2q'\delta) - p\delta.$$

The first-order derivative yields $q_d = \frac{\mu+\delta}{3}$, and therefore $p = \gamma\left(\frac{2\mu-\delta}{3}\right)$. The feasibility conditions are that $p > \gamma q'$ and $q' \geq \delta$. The former implies: $q' < \frac{2\mu-\delta}{3} \Rightarrow \overline{c} < p^* - \frac{\gamma\delta}{3}$. To satisfy the second condition we require $\delta \leq \frac{\mu}{2}$.

Case II (only part of the option is exercised)

The profit of the dominant firm is $\pi_d = pq_d - \frac{\gamma}{2}(q_d)^2 + \int_{q'-\delta}^{\mu-q_d} \gamma x dx - p(\mu - q_d + \delta - q')$,where we have used that $q_f = p/\gamma = \mu - q_d$. Simplifying,

$$\pi_d = \gamma(\mu - q_d)(2q_d + q' - \mu - \delta) + \frac{\gamma}{2}(\mu^2 + 2q'\delta - 2\mu q_d - q' - \delta^2).$$

The first-order condition yields $q_d = \frac{\mu}{2} - \left(\frac{q'-\delta}{4}\right)$ and therefore $p = \gamma\left(\frac{\mu}{2} + \frac{q'-\delta}{4}\right)$.For this solution to be an equilibrium the following two feasibility conditions must hold $i)$ $q_d > 0$, or $q' < 2\mu + \delta$; $ii)$

$\gamma(q' - \delta) < p < \gamma q'$, this condition can be rewritten as

$$\frac{2\mu - \delta}{3} < q' < \frac{2\mu}{3} + \delta,$$

which is stricter than condition i. The equivalent condition for $\overline{c}$ is: $p^* - \frac{\gamma\delta}{3} < \overline{c} < p^* + \gamma\delta$.

A.4 Proof of Proposition 4

The welfare impact of a baseload VPP (which we define as ΔW^B) is the same as the one of a baseload divestment. It is given by the reduction in costs faced by the competitive fringe due to its output reduction, minus the increase in cost for the dominant firm, due to its output increase:

$$\Delta W^B = \int_{\frac{2}{3}\mu - \frac{\delta}{3}}^{\frac{2}{3}\mu} \gamma x dx - \int_{\frac{\mu}{3}}^{\frac{\mu+\delta}{3}} \gamma x dx,$$

which simplifies to $\frac{\gamma\delta}{9}(\mu - \delta)$.

Recall that at the optimal divestment the price and the output are given by $p(\hat{c}) = \frac{\sqrt{6}}{4}\frac{\mu-\delta}{\gamma}$ and $q_d^{IV} = \frac{\mu-\delta}{\sqrt{6}}$. These results imply that the welfare impact of the optimal divestment (which we define as $\Delta\hat{W}$) is given by the following expression:

$$\begin{aligned}
\Delta\hat{W} &= \int_{\frac{\sqrt{6}}{4}(\mu-\delta)}^{\frac{2}{3}\mu} \gamma x dx - \int_{\frac{\mu}{3}}^{\frac{\mu-\delta}{\sqrt{6}}} \gamma x dx - \int_{\left(\frac{2\sqrt{6}}{3}-1\right)(\mu-\delta)-\delta}^{\frac{\sqrt{6}}{4}(\mu-\delta)} \gamma x dx \\
&= \gamma\left[\frac{5}{18}\mu^2 - \frac{11(\mu-\delta)^2}{24} + \frac{\left(\left(\frac{2\sqrt{6}}{3} - 1\right)(\mu-\delta) - \delta\right)}{2}\right] \\
&= \gamma\left[\left(\frac{119}{72} - \frac{2}{3}\sqrt{6}\right)\mu^2 + \frac{7}{8}\delta^2 - \left(\frac{7}{4} - \frac{2}{3}\sqrt{6}\right)\delta\mu\right].
\end{aligned}$$

We have that

$$\begin{aligned}
\Delta\hat{W} - \Delta W^B &= \gamma\left[\left(\frac{119}{72} - \frac{2}{3}\sqrt{6}\right)\mu^2 + \left(\frac{7}{8} + \frac{1}{9}\right)\delta^2 - \left(\frac{7}{4} - \frac{2}{3}\sqrt{6} + \frac{1}{9}\right)\delta\mu\right] \\
&= \gamma\left[\left(\frac{119}{72} - \frac{2}{3}\sqrt{6}\right)\mu^2 + \frac{71}{72}\delta^2 - \left(\frac{67}{36} - \frac{2}{3}\sqrt{6}\right)\delta\mu\right].
\end{aligned}$$

The gradient of $\Delta\hat{W} - \Delta W^B$ is

$$\bigtriangledown(\mu, \delta) = \left(\frac{d}{d\mu}\left(\Delta\hat{W} - \Delta W^B\right), \frac{d}{d\delta}\left(\Delta\hat{W} - \Delta W^B\right)\right),$$

with $\bigtriangledown(0,0) = 0$. The Hessian matrix of $\Delta\hat{W} - \Delta W^B$ is

$$H(\Delta\hat{W} - \Delta W^B) = \begin{bmatrix} 2\left(\frac{119}{72} - \frac{2}{3}\sqrt{6}\right) & -\left(\frac{67}{36} - \frac{2}{3}\sqrt{6}\right) \\ -\left(\frac{67}{36} - \frac{2}{3}\sqrt{6}\right) & 2\left(\frac{71}{72}\right) \end{bmatrix},$$

which is positive definite. Hence, $\mu = \delta = 0$ is a global minimum, where $\Delta\hat{W} - \Delta W^B = 0$. For any positive $\mu > 0$ and $\delta > 0$, we thus have that $\Delta\hat{W} - \Delta W^B > 0$.

A.5 Proof of Proposition 5

From the proof of Proposition 1 we have that for $\frac{\delta}{\mu} \in (0, 1 - \frac{12}{5\sqrt{6}})$ the cases i, ii, iii, iv and v are not feasible (case v requires that $\delta > \mu/6$), whereas Cases I, II, III, IV, V and VI are feasible depending on the location of q'. Using the proof of Proposition 1, we have that, for a given q',

- if $q' < \frac{\mu+\delta}{3}$, then q_d^I is the unique equilibrium.
- if $\frac{\mu+\delta}{3} \leq q' < \frac{\mu+2\delta}{3}$, then q_d^{II} is the unique equilibrium.
- if $\frac{\mu+2\delta}{3} \leq q' < \frac{3}{5}(\mu - \delta)$, then q_d^{III} is the unique equilibrium.
- if $\frac{3}{5}(\mu - \delta) \leq q' \leq \frac{3}{5}\mu + \delta$, then Cases III and IV overlap. From above, however, we have that $\hat{q}$, which is given by $\pi_d^{III} = \pi_d^{IV}$, is not contained in the range of q' that defines Case IV. As case i is not feasible, here q_d^{III} is the unique equilibrium.
- if $\frac{3}{5}\mu + \delta < q' < \frac{2}{3}(\mu - \delta)$, then Cases III and V overlap (since $\delta < \mu/25$). In this case the dominant firm will choose the equilibrium that yields the highest profit. Thus, Case III is the equilibrium outcome if $\pi_d^{III} > \pi_d^V$, and Case V is the equilibrium otherwise. Recall that $\pi_d^{III} = \frac{\gamma}{6}(\mu - \delta)^2$, whereas π_d^V is increasing in q':

$$\pi_d^V = \gamma(q' - \delta)(\mu - q' + \delta) - \frac{\gamma}{2}(\mu - q' + \delta)^2.$$

  Let $\hat{q}'$ be a value for q' so that $\pi_d^{III} = \pi_d^V$, then for $q' < \hat{q}'$ we have $\pi_d^{III} > \pi_d^V$, and for $q' > \hat{q}'$ we have $\pi_d^V > \pi_d^{III}$, provided that $\frac{3}{5}\mu + \delta < \hat{q}' < \frac{2}{3}(\mu - \delta)$. $\hat{q}'$ is thus given by

$$\gamma(\mu - q' + \delta)\left[(q' - \delta) - \frac{(\mu - q' + \delta)}{2}\right] = \frac{\gamma}{6}(\mu - \delta)^2,$$

  which can be rewritten as

$$-3q'^2 + 2(3\delta + 2\mu)q' - \frac{2}{3}(2\mu^2 + 5\delta^2 + 5\delta\mu) = 0.$$

  This yields two positive roots in q', but only one of them is contained in the region where

Case V is feasible:[17]

$$q' = \hat{q}' \equiv \frac{2}{3}\mu + \delta - \frac{1}{3}\sqrt{\delta(2\mu-\delta)}.$$

This root is contained in the region where Cases III and V overlap. This follows from the fact that $\pi_d^V > \pi_d^{III}$ at $q' = \frac{2}{3}(\mu-\delta)$, and $\pi_d^{III} > \pi_d^V$ at $q' = \frac{3}{5}\mu+\delta$. Since π_d^{III} is constant and π_d^V is increasing in q', we have that $\frac{3}{5}\mu+\delta < \hat{q}' < \frac{2}{3}(\mu-\delta)$. The price is given by $p = \gamma(q'-\delta)$, thus for $q' = \hat{q}'$ we have that $p(\gamma\hat{q}') = p^* - \frac{\gamma}{3}\sqrt{\delta(2\mu-\delta)}$.

- if $\frac{2}{3}(\mu-\delta) < q' < \frac{2}{3}\mu+\delta$, then only Case V applies, q_d^V is then the unique equilibrium.
- if $q' > \frac{2}{3}\mu+\delta$, then q_d^{VI} is the unique equilibrium.

Notice that the minimum p^{II} is achieved at $q' = \frac{\mu+2\delta}{3}$, where $p^{II} = p^* - \frac{2}{3}\gamma\delta$, and that the minimum price achieved when Case V is the only case which applies (defined as $\min p^V$) obtains at $q' = \frac{2}{3}(\mu-\delta)$, where $p^V = p^* - \frac{5}{3}\gamma\delta$. Therefore, for a given δ, the minimum prices that can be achieved in each region satisfy $\min p^V < \min p^{II} = p^{III} < p^I = p^* - \frac{1}{3}\gamma\delta < p^{VI} = p^*$. In the region where Cases III and V overlap, q' is lower than the lower bound of the region where only Case V exists and, moreover, p^V and π_d^V increase with q', thus $p(\gamma\hat{q}') < \min p^V$. Therefore, the optimal divestment is located at $\overline{c} = \hat{c} \equiv \gamma\hat{q}'$. Finally, $R(\frac{\delta}{\mu}) = \frac{p^*-p(\gamma\hat{q}')}{\Delta_p} = \frac{\sqrt{\delta(2\mu-\delta)}}{\delta} = \sqrt{\frac{2\mu}{\delta}-1}$.

A.6 Proof of Proposition 6

From the proof of Proposition 1 we have that for $\frac{\delta}{\mu} \in (1-\frac{2}{\sqrt{6}}, \frac{1}{2}]$ the Cases i, ii, iii and iv are not feasible, whereas Cases v, I, II, III, IV, V and VI are feasible. The range where Case v applies is $\frac{\mu}{2} < q' < \frac{\mu}{3}+\delta$. As it is shown in the proof of Proposition 1, the output of the dominant firm in Case v is given by $q_d = q' - \delta$ whilst the inverse demand curve is given by $p(q_d) = \frac{\gamma}{2}\left(\mu + q' - \delta - q^d\right)$. This in turn implies that $p^v = \frac{\gamma\mu}{2} \equiv p^c$. This means that if for a given q' Case v is the equilibrium outcome, q' also represents the optimal position of the divestment (though not necessarily unique), since it delivers the competitive price p^c.

Using the proof of Proposition 1, we have that, for a given q',

- if $\delta \geq \frac{\mu}{5}$, then only the Case v exists, so p^v is the unique equilibrium, for $q' \in \left(\frac{2}{3}(\mu-\delta), \frac{\mu}{3}+\delta\right)$.
- if $\delta < \frac{\mu}{5}$, then Cases III and v overlap for $\frac{\mu}{2} < q' \leq \frac{\mu}{3}+\delta$.

These conditions imply that if $\pi_d^v > \pi_d^{III}$ at $q' = \frac{\mu}{3}+\delta$, then setting $q' = \frac{\mu}{3}+\delta$ achieves the optimal divestment. As shown in the proof of Proposition 1, $\pi_d^{III} = \frac{\gamma}{6}(\mu-\delta)^2$. Using the expressions for price and quantity given above we also have that:

$$\pi_d^v = \frac{\gamma\mu}{2}\left(q'-\delta\right) - \frac{\gamma}{2}\left(q'-\delta\right)^2 = \frac{\gamma}{2}\left(q'-\delta\right)\left(\mu - q' + \delta\right).$$

[17] The second root is above the upper bound of the feasible region, i.e., $\frac{2}{3}\mu+\delta+\frac{1}{3}\sqrt{\delta(2\mu-\delta)} > \frac{2}{3}(\mu-\delta)$.

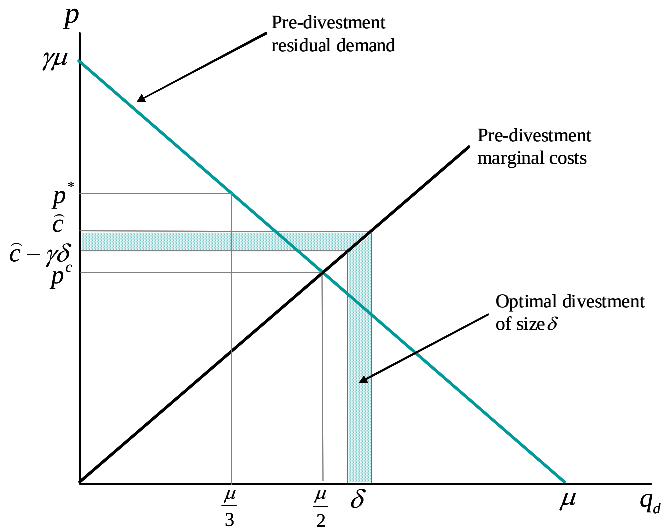

Figure 6: Position of the optimal divestment for $\delta = \frac{\mu}{20}$.

Setting $q' = \frac{\mu}{3} + \delta$ we have that $\pi_d^v > \pi_d^{III}$ if $\frac{1}{9}\mu^2 > \frac{\gamma}{6}\left(\mu - \delta\right)^2$, which is equivalent to $\frac{2}{3}\mu^2 > (\mu - \delta)^2$. In the range of δ considered here (i.e. for $\frac{\delta}{\mu} \in (1 - \frac{2}{\sqrt{6}}, \frac{1}{2}]$) this condition is satisfied, since the right hand side of the inequality is decreasing in δ, and it equals $\frac{2}{3}\mu^2$ for $\delta = \left(1 - \frac{2}{\sqrt{6}}\right)\mu$. This proves that setting $q' = \frac{\mu}{3} + \delta$ achieves the optimal divestment in the range of $\frac{\delta}{\mu}$ considered in this Proposition. For all other values of δ contained within the range considered in this Proposition (i.e. for $\delta > \left(1 - \frac{2}{\sqrt{6}}\right)\mu$), there exists a lower value for q' so that the equilibrium price is the competitive price. To see this, notice that

$$\frac{d\pi_d^V}{d\delta} = -\frac{d\pi_d^V}{dq'} = p^c - \gamma(q' - \delta),$$

which implies that for a slight increase in δ, there exists a slight decrease in q' so that π_d^V keeps constant. By contrast, for a slight increase in δ, π_d^{III} decreases. Therefore, for a higher δ, there exist multiple values for q' for which p^c is the equilibrium outcome (since $\pi_d^V > \pi_d^{III}$).

A.7 Illustration of the position of the optimal divestment (for $\delta = \frac{\mu}{20}$)

Figure 6 illustrates the position of the optimal divestment, relative to the pre-divestment marginal cost and residual demand functions of the dominant firm, for the case of $\delta = \frac{\mu}{20}$. As the figure shows the cost range of the optimal divestment is between the pre-divestment price and the competitive price. As it is explained in the main text, for divestments of intermediate size it is always the case that $\hat{c} \in (p^c, p^*)$.