Accepted Manuscript

Green competition, hybrid equilibrium, and establishment of a resale market

Arthur J. Caplan, Reza Oladiy

PII: S1059-0560(17)30958-9

DOI: 10.1016/j.iref.2018.03.025

Reference: REVECO 1626

To appear in: *International Review of Economics and Finance*

Received Date: 28 December 2017

Revised Date: 26 March 2018

Accepted Date: 29 March 2018

Please cite this article as: Caplan A.J. & Oladiy R., Green competition, hybrid equilibrium, and establishment of a resale market, *International Review of Economics and Finance* (2018), doi: 10.1016/j.iref.2018.03.025.

Green Competition, Hybrid Equilibrium, and Establishment of a Resale Market

Arthur J. Caplan*
Department of Applied Economics
Utah State University

Reza Oladi†
Department of Applied Economics
Utah State University

Abstract

This paper investigates competition between firms whose choices of how much "green effort" to devote to building their reputations as socially responsible producers are determined in the contexts of simultaneous-move and hybrid simultaneous/sequential-move Bertrand equilibria. We derive conditions under which (1) the inter-temporal, green-effort reaction function of the firm with the less-aggressive green strategy is non-monotonic, (2) the level of green effort chosen by the firm with the more-aggressive green strategy increases when it views itself as the leader in a hybrid game rather than moving concurrently in a simultaneous-choice game, and (3) the establishment of a resale market by the more aggressive firm acts as a substitute for its choice of green-effort level. The sufficiency conditions underlying these results impose qualitative restrictions on the more-aggressive firm's lagged (i.e., reputational) and contemporaneous cross effects of its green effort on demand for the less-aggressive firm's product, as well as on the less-aggressive firm's price markup and marginal cost associated with its production and green-effort choices, respectively.

JEL: D21, L13, M14

Keywords: green effort; Bertrand equilibrium; resale market

*Corresponding author: arthur.caplan@usu.edu. Caplan is Professor, Department of Applied Economics, Utah State University, 4835 Old Main Hill, Logan, Utah 84322-4835.

†Oladi is Associate Professor, Department of Applied Economics, Utah State University, 4835 Old Main Hill, Logan, Utah 84322-4835.

Green Competition, Hybrid Equilibrium, and Establishment of a Resale Market

Abstract

This paper investigates competition between firms whose choices of how much "green effort" to devote to building their reputations as socially responsible producers are determined in the contexts of simultaneous-move and hybrid simultaneous/sequential-move Bertrand equilibria. We derive conditions under which (1) the inter-temporal, green-effort reaction function of the firm with the less-aggressive green strategy is non-monotonic, (2) the level of green effort chosen by the firm with the more-aggressive green strategy increases when it views itself as the leader in a hybrid game rather than moving concurrently in a simultaneous-choice game, and (3) the establishment of a resale market by the more aggressive firm acts as a substitute for its choice of green-effort level. The sufficiency conditions underlying these results impose qualitative restrictions on the more-aggressive firm's lagged (i.e., reputational) and contemporaneous cross effects of its green effort on demand for the less-aggressive firm's product, as well as on the less-aggressive firm's price markup and marginal cost associated with its production and green-effort choices, respectively.

JEL: D21, L13, M14

Keywords: green effort; Bertrand equilibrium; resale market

1 Introduction

Why would a firm that has already earned a prodigious reputation for social, environmental, and corporate responsibility continually make costly investments to enhance its standing among consumers? From an economic standpoint (i.e., abstracting from potential non-economic reasons such as the company's "corporate culture"), the most plausible answer is that the firm believes demand for its product remains responsive enough to make marginal enhancements in its "green" reputation worth the investments; enhancements that induce substitution effects (i.e., demand shifts away from its competitor) and/or scale effects (entry of new consumers). In other words, the firm foresees potential gains from sustained engagement in "green competition" with its competitor(s).

Our notion of green competition is perhaps best exemplified by the behavior of reputably green firms in the electric vehicle (EV) and outdoor apparel industries. Founded by Elon Mask in 2003, Tesla Inc. initiated a revolution in the automobile industry via its design and engineering of zero-emission EVs with noticeably more efficient battery charging times and travel distances per charge. As described in O'Dell (2016), Tesla was the first automobile company "committed to the idea that the passenger car can be both exciting to drive and friendly to the environment, that performance and environmental sensibility are not mutually exclusive. The Tesla difference is that all that technology, power, and environmental friendliness comes in one package." As a result, Tesla has established (and is recurrently attempting to sustain) its reputation as the dominant firm in an increasingly competitive EV market (McCarthy, 2017).[1]

A second case-in-point is the outdoor-apparel firm Patagonia. Since the launching of its 1% For the Planet tithing program in 1985 to its becoming the outdoor apparel industry's sole registered B Corporation in 2011 to its most recent Responsible Economy "un-marketing" campaign, Patagonia has long been considered a paragon of social, environmental, and corporate responsibility for its efforts at reducing its environmental footprint in production (and more recently consumption).[2] Indeed, its efforts at meeting this multifaceted responsibility outweigh those of its larger competitors The North Face and Columbia to such an extent that Reinhardt et al. (2010 and 2014), O'Rourke and Strand (2016), and Hoffman (2012) each distinguish Patagonia as occupying a class all its own among its rivals.[3] Given their unique approaches to innovative design and environmental responsibility (which we henceforth denote as "green effort"), two questions naturally arise for game theorists.

First, what are the inter-temporal (i.e., lagged or reputational) effects of a more aggressive firm's green effort on that of its rivals? That is – in the context of our two examples – to what extent should we expect Tesla's and Patagonia's competitors to eventually engage in more aggressive green competition themselves?

[1] According to McCarthy (2017), Tesla was the EV market's dominant force in the first six months [of 2017] with its Models S and X accounting for 45 percent of all EV sales in the US. The Chevrolet Bolt and Nissan Leaf accounted for 16 and 15 percent of sales, respectively.

[2] B Corporations are for-profit companies certified by the global nonprofit B Lab to meet rigorous standards of social and environmental performance, accountability, and transparency. There are currently only 1700 certified B Corporations across 130 industries located in 50 countries worldwide (B Lab, 2016).

[3] Reinhardt et al. (2010 and 2014), O'Rourke and Strand (2016), and Hoffman (2012) provide exhaustive historical summaries and assessments of Patagonia's unique commitments and actions to reduce its footprint and lead and engage the corporate responsibility movement. For social media's perspective on Patagonia's recent Responsible Economy program see O'Brien (2012), Stevenson (2012), Voight (3013), and Ryan (2014). This program entails (1) creating cognitive dissonance (e.g., guilt, concern, and other forms of mental discomfort) in the minds of its consumers regarding their motivations for wanting to purchase new clothing to begin with, (2) creation of a company investment fund to invest in environmental activism startup companies, and (3) (a focus of this paper) the opening of used Patagonia clothing stores nationwide (including a partnership with ebay to facilitate online resale of its used clothing) (Ryan, 2014; Voight, 2013; Hoffman, 2012; O'Rourke and Strand, 2016).

Second, does the theorized extent of the aggressor firm's ambition depend upon the choice of equilibrium concept, e.g., when it comes to promoting its "responsible economy strategy" what effect does Patagonia "moving" simultaneously with, versus prior to its main competitor The North Face have on the extent to which Patagonia should exert green effort?

In this paper we take an initial step toward answering both questions by solving a vertical-differentiated-products model for both simultaneous-move and a hybrid of simultaneous-and sequential-move Bertrand equilibria. Even though we assume differentiated rather than homogeneous products, the model is firmly rooted in the class of exogenous-timing duopoly models studied by Maskin and Tirole (1988). As described in Section 2, these roots run even deeper in the strategic-investment literature. Despite the model's focus on capturing the unique features of green competition, i.e., competition between more aggressive green firms such as Tesla and Patagonia and their respective competitors – where the more aggressive firms are effectively pre-determined leaders in terms of the timing of moves and extent of green effort – our chosen equilibrium concepts align rather closely with the seminal studies of Fudenberg and Tirole (1984) and Bulow et al. (1985).[4] These equilibrium concepts provide a rich depiction of the circumstances under which two firms – one an aggressive green firm (henceforth, firm G) and the other noticeably less so (henceforth denoted as firm N) – become engaged in green competition, and how this competition influences their green-effort strategies.[5].

As shown in Section 2, we first coalesce a set of key (and, for the most part, standard) assumptions from the duopoly literature into three sufficiency conditions that underlie our findings (e.g., Fudenberg and Tirole, 1984). The first sufficiency condition requires that the "relative" component of firm G's green-reputational effect (i.e., the lagged cross-effect of G's green effort on the contemporaneous demand for firm N's product) outweighs its corresponding "absolute" component. Specifically, we assume that the extent to which firm G's lagged (e.g., period 1) green effort tempers the subsequent effects of its contemporaneous (e.g., period 2) green effort on contemporaneous demand for firm N's product, e.g., by raising the proverbial bar for G's contemporaneous effort to add to its reputational effects (the relative component), it must nevertheless

[4] Fudenberg and Tirole (1984) and Bulow et al. (1985) in turn descend from the earlier work of Spence (1977) and Dixit (1980).

[5] Since our focus is on competition between two rival firms in an industry rather than on economy-wide production levels and their effects on other sectors of an economy, a partial equilibrium is the most appropriate framework within which to answer our specific research questions. This approach aligns with a vast literature, where a variety of issues faced by rival firms are addressed (see Fudenberg and Tirole, 1984, Motta, 1993, Lee and Wong, 2005, Beladi and Oladi, 2011, and more recently Lee, 2017). This said, sector-level production and its economy-wide effects nevertheless present important research questions of their own (see Beladi et al., 2013, and Tai et al., 2015). As suggested by an anonymous reviewer our model can be extended in future research to a general-equilibrium framework by, for example, adding a perfectly competitive composite-good sector

outweigh the cross effect of G's lagged green effort itself (the absolute component). The second condition requires that the cross effect of firm G's contemporaneous green effort on firm N's contemporary demand must also outweigh the absolute component of G's lagged effort. The third condition requires that the firm experiencing the lagged cross effects (e.g., firm N) is nevertheless capable of maintaining a sufficiently high price markup and/or sufficiently low marginal cost of production in the face of these cross effects.

We obtain three main results. First, we uncover the conditions under which firm N's inter-temporal, green-effort reaction function is non-monotonic. In particular, while its best lagged response to an increase in firm G's effort is to increase its own green effort (e.g., in an attempt to better compete with G on the "green margin"), N's best concurrent response is to instead decrease its effort (e.g., to withdraw from competing on the green margin). Maskin and Tirole (1988) similarly demonstrate the existence of non-monotonic, price reaction functions for duopolistic firms producing homogeneous goods in exogenous-timing games. However, to our knowledge this is the first instance where a non-monotonic quantity reaction function (for what we are calling green effort) arises in a differentiated-product, Bertrand-equilibrium setting.[6]

Second, to the extent that firm G views itself as the leader vis-a-vis firm N in building its reputation as the greener firm, and to the extent that the indirect effect of its contemporaneous green effort on its own consumer demand (working indirectly through firm N's own green effort) outweighs the indirect effect working through firm N's pricing strategy, firm G's optimal second-period effort will be larger than it otherwise would be if it instead viewed itself as choosing its effort simultaneously with firm N.[7] In other words, we are able to characterize the conditions under which the timing of moves on the effort, or quantity, margin in a Bertrand equilibrium induces more or less green effort from the focal firm (firm G). Third, but as importantly, we consider the possible establishment of a resale market for firm G's product and derive a necessary and sufficient condition for that market to act as a substitute for G's green effort. We show that this condition is met when the value of excess demand in the resale market is positively related to firm G's green effort. The next section presents and solves a simple model for both simultaneous-choice and hybrid Bertrand equilibria that provides answers to this study's two main questions. Section 3 introduces a resale

[6] It is not uncommon in the literature concerned with strategic interactions among firms with varying degrees of "greenness" to derive results contingent upon the relative strengths of what are often offsetting effects. For example, McGinty and de Vries (2009) find that subsidization of clean technology adoption reduces environmental damage when the substitution effect (reduction in pollution associated with the clean technology) outweighs the output effect (the extent to which the subsidy increases output).

[7] As demonstrated by Fudenberg and Tirole (1984), indirect effects in duopoly models can play exceedingly important roles in defining the motivations for, and determining the outcomes of, strategic behavior.

market (solely for firm G's product).[8] Section 4 concludes.

2 The Basic Model and Bertrand Equilibria

Let $y_t^i = y_t^i(\Omega_t^i)$ represent a continuous consumer demand function for firm i's product in period t, $i = N, P$ and $t = 1, 2$, where, again, $P(N)$ can be thought of as representing the more(less) aggressive firm with respect to its level of green effort. We define vectors Ω_t^i as $\Omega_1^i = (p_1^i, \phi_1^i; p_1^{-i}, \phi_1^{-i})$ and $\Omega_2^i = (p_2^i, \phi_1^i, \Delta^i; p_2^{-i}, \phi_1^{-i}, \Delta^{-i})$, where $\phi_t^i \in [0,1]$ and $\phi_t^{-i} \in [0,1]$ represent i's and $-i$'s efforts at building respective green reputations among their consumers (i.e., green efforts) in periods $t = 1, 2$, and $\phi_2^i - \phi_1^i \equiv \Delta^i \in [-1, 1]$ and $\phi_2^{-i} - \phi_1^{-i} \equiv \Delta^{-i} \in [-1, 1]$ represent the change in the levels of i's and $-i$'s green efforts between the first and second periods, respectively. Further, $p_t^i \geq 0$ and $p_t^{-i} \geq 0$, $t = 1, 2$, represent the prices charged by i and $-i$ for their respective outputs y_t^i and y_t^{-i}. Note that p_1^i and ϕ_1^i are firm i's first-period choice variables, and p_2^i and ϕ_2^i its choice variables in period two.[9] To simplify the ensuing analysis, and at the same time hone the model to better focus on the research questions at hand, we normalize firm N's first-period effort at $\phi_1^N = 0$. This simplification reflects the fact that determining a specific equilibrium level of ϕ_1^N is inessential for what follows.[10]

Assuming that firm i's second-period demand depends upon the between-period, or inter-temporal, change in its green effort (i.e., Δ^i), rather than simply effort undertaken in the second-period (i.e., ϕ_2^i), reflects a hysteresis-type effect inherent in building a reputation. In other words, prior effort to build a reputation (i.e., ϕ_1^i) establishes a benchmark for the current period (ϕ_2^i), wherein current-period effort is effectively weighed against the firm's established reputation in a relative sense (Δ^i), rather than considered independently from it solely in an absolute sense (i.e., solely via ϕ_1^i).[11] By accounting for both the relative and absolute effects associated with the establishment of a reputation in our model, we therefore extend the

[8] Restricting the establishment of a resale market solely for firm G's product, rather than for both G's and N's products, mirrors both the Patagonia and Tesla motifs that underlie our analysis.

[9] Aside from the well-known fact that price competition is generally more intensive than quantity competition in a practical sense, our choice of the Bertrand equilibrium concept seems more intuitive in our context of green competition because consumers balance their choice of greenness with the price they pay for it. Also see Motta (1993) for why the Bertrand equilibrium concept is more appropriate than Cournot for modeling quality-choice decisions.

[10] In their two-period model of entry-deterrence by an incumbent firm, Fudenberg and Tirole (1984) similarly focus their analysis on the second period once the entry decision has been made.

[11] This is another way of saying that the firms experience diminishing returns to green effort over time. Our assumption that the firms' demands depend solely upon contemporaneous prices, and thus do not exhibit a hysteresis effect similar to that based on the firms' green-effort choices, is consistent with the standard Markov pricing assumption adopted by Maskin and Tirole (1988).

imperfect-competition literature with respect to models where reputation is a central feature of the analysis (e.g., Horner, 2002) and where it is not (e.g., Fudenberg and Tirole, 1984).[12]

With respect to own-price and own-effort effects, we invoke the following four customary assumptions concerning firm behavior in a dynamic duopolistic framework,

A1 Consumer demand for firm i's product is decreasing and linear in its (contemporaneous) price (i.e., $\partial y_t^i/\partial p_t^i < 0$ and $\partial^2 y_t^i/\partial p_t^{i2} = 0$, $i = N, G$, $t = 1, 2$).

A2 Firm i's second-period demand is increasing and concave in its second-period green effort level (i.e., $\partial y_2^i/\partial \phi_2^i > 0$ and $\partial^2 y_2^i/\partial \phi_2^{i2} \leq 0$, $i = N, G$).[13]

A3 Firm G's first-period demand is increasing and concave in its first-period green effort level (i.e., $\partial y_1^G/\partial \phi_1^G > 0$ and $\partial^2 y_1^G/\partial \phi_1^{G2} \leq 0$).[14]

A4 Increased green effort in the second period by firm N helps offset the negative effect in consumer demand for its product of an increase in its second-period price (i.e., $\partial^2 y_2^N/\partial p_2^N \partial \phi_2^N > 0$).[15]

With respect to contemporaneous cross effects we further assume,[16]

A5 Firm G's second-period demand responds positively to increases in firm N's second-period price ($\partial y_2^G/\partial p_2^G > 0$) and negatively to increases in N's second-period effort level ($\partial y_2^G/\partial \phi_2^G < 0$), i.e., firm G's product is a contemporaneous substitute for firm N's product with respect to both price and green effort.

A6 Firm N's demand responds negatively to contemporaneous increases in firm G's effort level (in particular, $\partial y_t^N/\partial \phi_t^G < 0, \partial^2 y_t^N/\partial p_t^N \partial \phi_t^G < 0$, $t = 1, 2$, and $\partial^2 y_2^N/\partial \phi_2^N \partial \phi_2^G < 0$), i.e., firm G's product is a contemporaneous substitute for firm N's with respect to green effort.[17]

Finally, with respect to lagged cross effects we assume,

[12]In each of these models the building of a reputation is considered solely in what we have defined as the absolute sense.

[13]Except when necessary, we can write $\partial y_2^i/\partial \phi_2^i$ rather than its longer version $(\partial y_2^i/\partial \Delta^i)(\partial \Delta^i/\partial \phi_2^i)$, because by definition $\partial \Delta^i/\partial \phi_2^i = 1, i = N, G$. This abbreviated notation is also used to denote the inter-temporal effect of firm G's choice of ϕ_1^P on y_2^G, i.e., $(\partial y_2^G/\partial \Delta^G)(\partial \Delta^G/\partial \phi_1^G) = \partial y_2^G/\partial \phi_1^G$, since by definition $\partial \Delta^G/\partial \phi_1^G = -1$.

[14]We do not definitively sign the inter-temporal effect of firm G's first-period effort level on its second-period demand because although the direct effect is assumed positive (i.e., $\partial y_2^G/\partial \phi_1^G > 0$), the indirect effect is negative (i.e., $(\partial y_2^G/\partial \Delta^G)(\partial \Delta^G/\partial \phi_1^G) < 0$)).

[15]Hence by Young's Theorem, $\partial^2 y_2^N/\partial \phi_2^N \partial p_2^N > 0$, i.e., the positive effect of firm N's second-period effort level on its demand is enhanced by contemporaneous increases in its price.

[16]These types of assumptions on cross effects are inherent in the imperfect competition literature. For example, in their entry-deterrence model of Bertrand competition with differentiated goods Fudenberg and Tirole (1984) assume that the firm's price and marginal revenue both respond positively to the competitor's price.

[17]Note that, similar to how the own-effort effects are denoted above, we can write $\partial y_2^N/\partial \phi_2^G$ rather than $\partial y_2^N/\partial \Delta^G$, $\partial^2 y_2^N/\partial p_2^N \partial \phi_2^G < 0$ rather than $\partial^2 y_2^N/\partial p_2^N \partial \Delta^G$, and $\partial^2 y_2^N/\partial \phi_2^N \partial \phi_2^G$ rather than $\partial^2 y_2^N/\partial \phi_2^N \partial \Delta^G$.

A7 Firm N's second-period demand responds negatively to increases in firm G's first-period effort level in an *absolute* sense (i.e., $\partial y_2^N/\partial\phi_1^G < 0$, $\partial^2 y_2^N/\partial p_2^N \partial\phi_1^G < 0$, and $\partial^2 y_2^N/\partial\phi_2^N \partial\phi_1^G < 0$). Thus, in solely an absolute sense firm G's product is a lagged substitute for firm N's with respect to green effort.

A8 Firm N's second-period demand responds positively to increases in firm G's first-period effort level in a *relative* sense (i.e., $(\partial y_2^N/\partial\Delta^G)(\partial\Delta^G/\partial\phi_1^G) = -\partial y_2^N/\partial\Delta^G > 0$, $(\partial^2 y_2^N/\partial p_2^N)(\partial\Delta^G/\partial\phi_1^G) = -\partial^2 y_2^N/\partial p_2^N \partial\Delta^G > 0$, and $(\partial^2 y_2^N/\partial\phi_2^N \partial\Delta^G)(\partial\Delta^G/\partial\phi_1^G) = -\partial^2 y_2^N/\partial\phi_2^N \partial\Delta^G > 0$). Thus, in solely a relative sense firm G's product is a lagged complement of firm N's with respect to green effort.

Given Assumptions A7 and A8, we note that the full (i.e., absolute plus relative) inter-temporal cross effects associated with increases in G's first-period effort level (on N's second-period demand) are written respectively as $\partial y_2^N/\partial\phi_1^G - \partial y_2^N/\partial\Delta^G$, $\partial^2 y_2^N/\partial p_2^N \partial\phi_1^G - \partial^2 y_2^N/\partial p_2^N \partial\Delta^G$, and $\partial^2 y_2^N/\partial\phi_2^N \partial\phi_1^G - \partial^2 y_2^N/\partial\phi_2^N \partial\Delta^G$. Since each of the terms in these respective expressions are negative, we are therefore precluded from unambiguously signing the full inter-temporal cross effects overall based upon these two assumptions alone. To overcome this indeterminacy, we adopt the standing assumption-cum-sufficiency condition that, all else equal, the relative cross effects outweigh their corresponding absolute cross effects at any given $\Omega_t^i, i = N,G, t = 1,2$, which reflects a presumed diminishing return to lagged cross effects for firm G over time. As a result, each of the full, inter-temporal cross effects are positive, which, for future reference, is stated formally as Sufficiency Condition 1.

Sufficiency Condition 1. *The relative cross effects of firm G's lagged green effort on the demand for firm N's product outweigh their corresponding absolute cross effects, i.e.,* $\partial y_2^N/\partial\phi_1^G - \partial y_2^N/\partial\Delta^G > 0$, $\partial^2 y_2^N/\partial p_2^N \partial\phi_1^G - \partial^2 y_2^N/\partial p_2^N \partial\Delta^G > 0$, *and* $\partial^2 y_2^N/\partial\phi_2^N \partial\phi_1^G - \partial^2 y_2^N/\partial\phi_2^N \partial\Delta^G > 0$, *at any given* Ω_t^i, $i = N,G$, $t = 1,2$. *Thus, firm G's full, inter-temporal cross effects are each positive.*

As a natural follow-on to Sufficiency Condition 1, we state a second condition that compares the contemporaneous cross effect of firm G's green effort with its lagged absolute cross effect. In particular, we assume that, as with the comparison between relative and absolute lagged cross effects in Sufficiency Condition 1, firm G's contemporaneous cross effect on firm N's demand also outweighs its lagged absolute cross effect.

Sufficiency Condition 2. *The contemporaneous cross effect of firm G's green effort on the demand for firm N's product outweighs its lagged absolute cross effect, i.e.,* $\frac{\partial y_2^N}{\partial\phi_2^G} < \frac{\partial y_2^N}{\partial\phi_1^G} < 0$.

In relation to the specific brand of green competition we envision in this paper, e.g., between firms such as Tesla and Nissan, on the one hand, and Patagonia and The North Face on the other, it could very well be that, for instance, Patagonia expects to induce a large contemporaneous cross effect on The North Face with its Responsible Economy strategy, perhaps in unwitting recognition of what we have characterized in Sufficiency Conditions 1 and 2 as diminishing returns to lagged green effort and thus a relatively stronger return to contemporaneous green effort. To see this, recall that creating cognitive dissonance (e.g., guilt, concern, and other forms of mental discomfort) in the minds of its consumers regarding their motivations for desiring new clothing to begin with is one facet of Patagonia's strategy. Thus, Patagonia seems willing to sacrifice its own sales on the proverbial altar of an industry-wide reduction in demand. To the extent that this component of its strategy is successful, then, as Ryan (2014) points out, Patagonia can only "win" if The North Face's sales are more adversely affected than its own, in which case Patagonia would indeed be banking on relatively large, negative, contemporaneous cross effects of its Responsible Economy strategy on The North Face's consumer demand.[18]

Given the above definitions firm i's (long-run) profit is defined as,

$$\pi^i = p_1^i y_1^i - c^i\left(y_1^i, \phi_1^i\right) + \beta\left[p_2^i y_2^i - c^i\left(y_2^i, \phi_2^i\right)\right] \quad i = G, N \tag{1}$$

where β represents a common discount factor, and $c^i\left(y_t^i, \phi_t^i\right)$, $i = N, G$, $t = 1, 2$, represents firm i's total cost in period t, which is assumed increasing in both y_t^i and ϕ_t^i, continuous, and convex. Therefore, due to our previously mentioned assumptions on the firm's consumer demand functions (Assumptions A1 – A4) and the curvature conditions on c_t^i, π^i is continuous and concave. Optimality conditions for an interior, simultaneous-choice (i.e., "open-loop") Bertrand equilibrium are provided in Appendix A (and a brief discussion of the existence properties of the equilibrium is provided in Appendix B).[19] The key results stemming from these conditions are,

$$p_t^i > \frac{\partial c^i\left(y_t^i, \phi_t^i\right)}{\partial y_t^i} \quad t = 1, 2, \quad i = G, N \tag{2}$$

$$\left(p_2^i - \frac{\partial c^i(y_2^i, \phi_2^i)}{\partial y_2^i}\right)\frac{\partial y_2^i}{\partial \phi_2^i} = \frac{\partial c^i\left(y_2^i, \phi_2^i\right)}{\partial \phi_2^i} > 0 \quad i = G, N. \tag{3}$$

[18]Given the relative sizes of the firms considered in this paper, i.e., Tesla, Patagonia, and their respective competitors, we assume that no firms choose to exit the market as an equilibrium strategy.

[19]Sufficient conditions for the resulting equilibrium follow directly from our curvature conditions on $c_i(y_t^i, \phi_t^i)$, $i = N, G$, $t = 1, 2$.

Equation (2) is the standard Bertrand mark-up pricing rule for firms. Equation (3) is the optimality condition governing a firm's second-period effort level. For future reference, we henceforth denote firm G's second-period effort level as $\phi_2^{G^*}$. This condition states that the marginal benefit of effort (i.e., the net value of additional output - via the price markup - that is brought about by additional effort) equals the associated marginal cost of effort at the optimal solution.

Appendix C provides derivations for the corresponding set of firm N's reaction functions. Of particular interest are reaction functions $\partial\phi_2^N/\partial\phi_1^G$ and $\partial\phi_2^N/\partial\phi_2^G$, which measure the lagged and contemporaneous cross effects, respectively, of firm G's effort levels on firm N's second-period effort level. As shown in the appendix, invoking Sufficiency Conditions 1 and 2 results in $\partial\phi_2^N/\partial\phi_1^G > 0$, i.e., all else equal, firm N responds to increases in G's first-period effort by increasing its own effort level in the second period. Firm N's response to G's second-period effort, $\partial\phi_2^N/\partial\phi_2^G$, is also ambiguous in general. The key expression (or what Bulow et al. (1985) label firm P's "strategic term" and Fudenberg and Tirole (1984) label as "strategic effect") governing its sign is reproduced here for easy reference (equation (C.10) from Appendix C),

$$J = \left(p_2^N - \frac{\partial c^N(y_2^N,\phi_2^N)}{\partial y_2^N}\right)\frac{\partial^2 y_2^N}{\partial\phi_2^N\partial\phi_2^G} - \frac{\partial^2 c^N(y_2^N,\phi_2^N)}{\partial {y_2^N}^2}\frac{\partial y_2^N}{\partial\phi_2^N}\frac{\partial y_2^N}{\partial\phi_2^G} - \frac{\partial^2 c^N(y_2^N,\phi_2^N)}{\partial\phi_2^N\partial y_2^N}\frac{\partial y_2^N}{\partial\phi_2^G}. \tag{4}$$

As we now show below, the sign of J plays a crucial role in the signing of $\partial\phi_2^N/\partial\phi_2^G$. In particular, $J < 0$ is a necessary condition for $\partial\phi_2^N/\partial\phi_2^G < 0$. By equation (2) and Assumption A6, J's first term is negative. This term measures the extent to which firm G's second-period effort level reduces the marginal benefit of N's second-period effort. The latter two terms together account for the marginal effect of G's second-period effort level on the marginal cost of N's second-period effort. Both terms are positive via Assumptions A1 – A6 for firm N, as well as the curvature conditions on c^N. This leads to a third sufficiency condition for the purposes of our analysis.

Sufficiency Condition 3. *All else equal, $J < 0$ holds in equilibrium for large-enough mark-up pricing and/or small-enough marginal-cost effects (i.e., $\partial^2 c^N/\partial {y_2^N}^2$ and $\partial^2 c^N/\partial\phi_2^N\partial y_2^N$) incurred by firm N in response to firm G's second-period effort level.*

In other words, given the extent to which firm G's second-period effort level affects both N's output (directly via $\partial y_2^N/\partial\phi_2^G < 0$) and effort (indirectly via $\partial^2 y_2^N/\partial\phi_2^N\partial\phi_2^G < 0$), $J < 0$ is more likely to hold the larger is N's price markup in equilibrium and/or the smaller are the marginal effects of N's output on its marginal production costs of both output, $\partial c^N/\partial y_2^N$, and effort, $\partial c^N/\partial \phi_2^N$. Succinctly put, $J < 0$ is more likely the more capable firm N is of maintaining both a large price markup and/or low marginal costs associated with additional output and effort. It is noteworthy that the large markup requirement is more likely to be met in a duopoly market, since price markups are monotonically decreasing in the number of firms as long as the firms remain small enough relative to their particular niche (Mas-Colell et al., 1995). These results are compiled in Proposition 1.

Proposition 1. *Given Sufficiency Conditions 1 – 3 firm N's inter-temporal ϕ_2^N-reaction function is non-monotonic. Specifically, N's second-period effort responds positively to firm G's first-period effort level, i.e., $\partial \phi_2^N/\partial \phi_1^G > 0$, and negatively to G's second-period effort level, i.e., $\partial \phi_2^N/\partial \phi_2^G < 0$.*[20]

Proof. See Appendix C. □

Thus, Proposition 1 establishes the condition under which firm N's best lagged response to an increase in firm G's effort is to increase its own effort (e.g., in an attempt to better compete with P on the "green margin"), but where N's best concurrent response is to instead decrease its effort (e.g., to withdraw from competing on the green margin). Again with respect to green competition between Patagonia and The North Face, Ryan's (2014) assessment of Patagonia's marketing approach suggests that Patagonia may indeed be banking on this type of outcome, particularly with respect to The North Face's concurrent reaction to Patagonia's Responsible Economics strategy.[21]

We end this section with an interesting comparison between the simultaneous- and sequential-choice versions of the Bertrand equilibrium concept in the context of our model. If we instead adopt a hybrid simultaneous/sequential-choice equilibrium concept, where the two firms continue to set their prices simultaneously but firm G now acts as a Stackelberg leader in choosing its second-period effort level, we are able to isolate the condition under which firm G's second-period effort level will increase relative to the simultaneous-choice case.[22] To see this result, we begin by rewriting equation (3) to reflect the fact that in

[20] It is interesting to note from Appendix C that in the absence of Sufficiency Conditions 1 and 2, N's inter-temporal ϕ_2^N-reaction function is monotonically decreasing in ϕ_1^G and ϕ_2^G. To the contrary, merely by Sufficiency Condition 3 ($J < 0$), N's inter-temporal p_2^N-reaction function is monotonically increasing in p_1^G and p_2^G. Derivations for N's inter-temporal p_2^N-reaction function are available from the authors upon request.

[21] Firm N's concurrent response resembles what Maskin and Tirole (1988) have labeled the "relenting phase" in a firm's pricing strategy, when the firm eventually chooses to stop competing with its rival in a price war (involving a homogeneous good) and raises its price. Price wars therefore represent a case of non-monotonic reaction functions for the class of homogeneous goods.

[22] The hybrid equilibrium concept seems to mirror the current state of green competition between Patagonia and The North Face as described in Ryan (2014), where Patagonia has taken the lead on pursuing a more aggressive green strategy rather than a more aggressive pricing strategy. The same can be said about Tesla's approach to green competition as well. As Halla (2015) and DeBord

a subgame perfect equilibrium firm G, as the leader, accommodates in its profit-maximization problem N's second-period price and effort responses to its (G's) choice of effort level.[23] Equation (3) therefore becomes,

$$\left(p_2^G - \frac{\partial c^G(y_2^G, \phi_2^G)}{\partial y_2^G}\right)\left(\frac{\partial y_2^G}{\partial \phi_2^G} + \Psi^G\right) = \frac{\partial c^G(y_2^G, \phi_2^G)}{\partial \phi_2^G} > 0 \tag{5}$$

where $\Psi^G \equiv (\partial y_2^G/\partial p_2^N)(\partial p_2^N \partial \phi_2^G) + (\partial y_2^G/\partial \phi_2^N)(\partial \phi_2^N/\partial \phi_2^G)$, and we denote G's optimal second-period effort level (which is governed by equation (5)), as $\phi_2^{G^{**}}$.[24] The two terms in Ψ^G account for the indirect effects of firm G's second-period choice of effort on consumer demand for its product, as this choice in turn affects firm N's second-period choices of price and effort level, respectively. By Assumptions A1 – A4, the comparative static results for $\partial p_2^N/\partial \phi_2^G$ and $\partial \phi_2^N/\partial \phi_2^G$ derived in Appendix C, and Proposition 1, we know that Ψ^G's first term is negative and its second term is positive. Thus,

$$\Psi^G > (<) 0 \quad iff \quad \frac{\partial y_2^G}{\partial \phi_2^N}\frac{\partial \phi_2^N}{\partial \phi_2^G} > (<) - \frac{\partial y_2^G}{\partial p_2^N}\frac{\partial p_2^N}{\partial \phi_2^G} \tag{6}$$

That is, $\Psi^G > (<) 0$ as the indirect effect of firm G's second-period choice of effort working through ϕ_2^N exceeds (is exceeded by) the indirect effect working through p_2^N. Comparing (3) with (5), and appealing to (6), leads to our second proposition.

Proposition 2. *Given Sufficiency Conditions 1 – 3, if* $\Psi^G > (<) 0$ *then* $\phi_2^{G^{**}} > (<) \phi_2^{G^*}$.

Proof. Assume $\Psi^G > 0$. Plugging $\phi_2^{G^*}$ (which solves condition (3)) into (5) results in $\left(p_2^G - \partial c^G(y_2^G, \phi_2^G)/\partial y_2^G\right)$ $\left(\partial y_2^G/\partial \phi_2^G + \Psi^G\right) > \partial c^G(y_2^G, \phi_2^G)/\partial \phi_2^G$. Given our assumed curvature conditions on c^G and Assumptions A1 – A4, increases in ϕ_2^G away from $\phi_2^{G^*}$ are necessary to satisfy (5) with equality. Thus, $\phi_2^{G^{**}} > \phi_2^{G^*}$, and vice-versa for $\Psi^G < 0$. □

Proposition 2 therefore establishes the condition under which firm G's second-period effort level in a subgame perfect equilibrium of the hybrid game exceeds its equilibrium effort level in the simultaneous-choice game. As with Proposition 1, Proposition 2 provides a possible theoretical rationale for Tesla's and Patagonia's historically more-aggressive green strategies. For example, to the extent that Tesla views

(2016) point out, Tesla has been considerably more forward thinking on margins such as developing a nationwide "supercharging" infrastructure (e.g. charging station networks, high-performance batteries, and "battery swap" pilot programs) to support its EV business, as opposed to relying on a more competitive pricing strategy to increase sales per se.

[23] Fudenberg and Tirole (1984) liken this form of accommodation by firm G to firm G's accounting for the possibility of strategic investment on the part of firm N.

[24] Note that equation (3) is the sole condition from the simultaneous-choice equilibrium that is altered in the hybrid equilibrium.

itself as the leader vis-a-vis its competitor bloc in building its reputation as the greener firm *and* to the extent that the indirect effect on its consumer demand of its current reputation-building effort (working through its competitors' own reputation-building efforts) outweighs the indirect effect working through the its competitors' pricing strategies, Tesla's optimal second-period effort will be larger than it otherwise would be if it instead viewed itself as choosing its effort simultaneously with its competitors.

Although Proposition 2 is a unique result in the investment literature – based as it is upon a comparison of the relative sizes of two indirect effects rather than on a standard comparison between direct and indirect effects – it nevertheless has an antecedent in Fudenberg and Tirole's (1984) model of an incumbent's strategic investment in advertising and research and development (R&D) to deter entry and Bulow et al.'s (1985) model of strategic behavior in a multimarket oligopoly. In their model, Fudenberg and Tirole (1984) show that when facing a potential entrant, the incumbent's (their focal firm's) own second-period price will respond positively to its advertising effort when the incumbent's profit and marginal profit increase with the entrant's price (standard assumptions) and its second-period reaction function is steeper than the entrant's.[25] Although the incumbent's advertising effort is larger in a perfect equilibrium relative to an open-loop equilibrium, the incumbent nevertheless under-invests to deter entry when the direct effect that its advertising effort has on reducing the entrant's potential market-share outweighs the effort's indirect effect on the entrant's price.

As shown above, in the case of our focal firm (firm G) the relative sizes of the cross effects associated with its level of effort play a similarly crucial role in determining the focal firm's behavior across different types of equilibria. We consider the cross effects of the focal firm's effort on the effort level of the non-focal firm, not on the non-focal firm's price as in Fudenberg and Tirole (1984) or profitability as in Bulow et al. (1985). Unlike these two previous studies, we find that it is a comparison of two indirect effects associated with the focal firm's choice of effort that ultimately matter, not a comparison between direct and indirect effects.[26]

[25] The authors wittily label this type of incumbent a "pacifist fat cat".

[26] The own and cross effects that evolve from Bulow et al.'s (1985) duopoly model are most similar to ours. A notable difference is their assumption of monotonic reaction functions – the slopes of which depend upon whether the firms' products are strategic substitutes or complements (defined according to whether one firm's multi-market or inter-temporal quantity effect on the other firm's marginal profitability is respectively negative or positive). In our model we effectively assume the firms' products are strategic substitutes, but, as shown in Proposition 1, we nevertheless are able to derive non-monotonic reaction functions because of our identification of both contemporaneous and lagged terms in the firms' inter-temporal cross effects.

3 The Effects of a Resale Market

As stated in Section 1, establishment of respective resale markets for Patagonia's outdoor apparel and Tesla's EVs are central features of these companies' business strategies. This section investigates the extent to which the introduction of a resale market for its product impacts firm G's second-period effort level.[27] Toward this end, we must first define four new terms. Let γ_2^u and v_2^u represent the price firm G pays and charges for its used product, respectively. Further, let $\chi_2^u = \chi^u\left(\Omega_2^G\right)$ and $x_2^u = x^u\left(\Omega_2^G\right)$ represent the corresponding amounts of used product supplied and demanded by firm G's consumers, respectively, where vector Ω_2^G is now expanded to include γ_2^u and v_2^u.

We henceforth make the following assumptions regarding the demand for firm G's used product.

B1 The amount of used product demanded by its customers in the second period is positively related to firm G's respective green-effort levels, i.e., $\partial x_2^u/\partial \phi_t^G > 0$, $t = 1, 2$, as well as to G's second-period price for new product, i.e., $\partial x_2^u/\partial p_2^G > 0$, implying that G's consumers see the firm's new and used products as being gross substitutes.

B2 To the contrary, firm G's used-product demand is negatively related to its own price, i.e., $\partial x_2^u/\partial v_2^u > 0$, and unrelated to the price firm G pays for its used merchandise, i.e., $\partial x_2^u/\partial \gamma_2^u = 0$.

Assumption B2 embodies a no-arbitrage condition across the demand and supply sides of the resale market for firm G's consumers. The following two assumptions apply to the used product supplied by firm G's customers.

B3 The amount of used product supplied by firm G's customers in the second period is positively related to the purchase price offered by G, i.e., $\partial \chi_2^u/\partial \gamma_2^G > 0$, but negatively related to G's second-period prices for its new and used products, i.e., $\partial \chi_2^u/\partial p_2^G < 0$ and $\partial \chi_2^u/\partial v_2^u < 0$, respectively.

In other words, as the prices for a replacement product – either new or used – increase, more consumers choose to hold onto what they currently own rather than sell it back to firm G.

B4 The direction of the relationship between used product supplied to firm G and G's effort level in the second period, i.e., the sign of $\partial \chi_2^u/\partial \phi_2^G$, is ambiguous.

[27] Numerous questions of interest can be addressed regarding resale markets. For example, as one reviewer has suggested, the effects of technical progress on resale prices merits further investigation. While this is an interesting research question in and of itself, it is obviously beyond the scope of the current paper. Rather, our focus is on the effect of establishing resale market on the extent of green competition among rival firms.

As shown below, the equilibrium value of $\partial\chi_2^u/\partial\phi_2^G$ forms the basis of a necessary and sufficient condition for this section's key finding concerning the substitutability of a resale market for green effort on the part of firm G.

Given the existence of its resale market, firm G's profit can be written as,[28]

$$\pi^G = p_1^G y_1^G - c^G\left(y_1^G, \phi_1^G\right) + \beta\left[p_2^G y_2^G + v_2^u x_2^u - \gamma_2^u \chi_2^u - c^G\left(y_2^G, \phi_2^G\right)\right] \tag{7}$$

Optimality conditions for this problem are provided in Appendix D. Of particular interest are conditions (D.4) and (D.2) from this appendix, which determine firm G's choices of ϕ_2^G and p_2^G, respectively. For future reference, we denote firm G's optimal choice of ϕ_2^G in the presence of a resale market for its product as $\tilde{\phi}_2^G$. Taking the ratio of these two equations results in,

$$\frac{\left(p_2^G - \frac{\partial c^G}{\partial y_2^G}\right)\frac{\partial y_2^G}{\partial \phi_2^G} - \frac{\partial c^G}{\partial \phi_2^G}}{\left(p_2^G - \frac{\partial c^G}{\partial y_2^G}\right)\frac{\partial y_2^G}{\partial p_2^G} + y_2^G} \equiv \Gamma^G = \Lambda^G \equiv \frac{\gamma_2^u \frac{\partial \chi_2^u}{\partial \phi_2^G} - v_2^u \frac{\partial x_2^u}{\partial \phi_2^G}}{\gamma_2^u \frac{\partial \chi_2^u}{\partial p_2^G} - v_2^u \frac{\partial x_2^u}{\partial p_2^G}}. \tag{8}$$

To the contrary, the corresponding ratio of (A.2) and (A.1) from Appendix A yields $\Gamma^G(\phi_2^{p^*}) = 0$, which leads to our final proposition.

Proposition 3. *For given p_2^G, $\phi_2^{G^*} > (<)\tilde{\phi}_2^G$ iff $\gamma_2^u \frac{\partial \chi_2^u}{\partial \phi_2^G} > (<) v_2^u \frac{\partial x_2^u}{\partial \phi_2^G}$.*

Proof. Given Assumptions B1 and B3, the denominator of Λ^G is negative. Again given Assumption B1, we see from the numerator of Λ^G that $\Lambda^G > (<)0$ as $\gamma_2^u\partial\chi_2^u/\partial\phi_2^G < (>) v_2^u\partial x_2^u/\partial\phi_2^G$. Assume $\Lambda^G(\tilde{\phi}_2^G) > 0$ (and thus by definition $\gamma_2^u\partial\chi_2^u/\partial\phi_2^G < v_2^u\partial x_2^u/\partial\phi_2^G$). Plugging $\phi_2^{G^*}$ (which, again, solves $\Gamma^G(\phi_2^{p^*}) = 0$ for given p_2^G) into the left-hand side of (8) yields $\Gamma^G(\phi_2^{G^*}) < \Lambda^G(\tilde{\phi}^G)$. Given Assumptions A1 – A3 and our assumed curvature conditions on c^G, decreases in ϕ_2^G away from $\phi_2^{G^*}$ are therefore necessary to satisfy (8) with equality at $\tilde{\phi}_2^G$. Thus, $\phi_2^{G^*} > \tilde{\phi}_2^G$ when $\gamma_2^u(\partial\chi_2^u/\partial\phi_2^G) < v_2^u(\partial x_2^u/\partial\phi_2^G)$, and vice-versa for $\gamma_2^u(\partial\chi_2^u/\partial\phi_2^G) > v_2^u(\partial x_2^u/\partial\phi_2^G)$ evaluated at $\tilde{\phi}_2^G$. □

Proposition 3 states a necessary and sufficient condition for green effort and the establishment of a resale market by firm G to effectively act as substitutes for one another in an equilibrium. "Substitutes" in this context means that G's second-period equilibrium effort level in the presence of a resale market is less than its equilibrium effort level in the absence of a resale market, or $\phi_2^{G^*} > \tilde{\phi}_2^G$. The condition for substitutability

[28] It is therefore assumed that in equilibrium $v_2^u x_2^u - \gamma_2^u \chi_2^u > 0$ is at least as large as G's total costs of operating its resale business.

states that, at equilibrium $\tilde{\phi}_2^G$, the marginal benefit of green effort as it relates to an increase in used product sold to consumers ($v_2^u \frac{\partial x_2^u}{\partial \phi_2^G}$) exceeds the marginal cost of that effort as it relates to an increase in used product purchased by firm G from consumers ($\gamma_2^u \frac{\partial \chi_2^u}{\partial \phi_2^G}$). Alternatively, if we first rewrite the sustainability condition as $v_2^u \frac{\partial x_2^u}{\partial \phi_2^G} - \gamma_2^u \frac{\partial \chi_2^u}{\partial \phi_2^G} > 0$, we can think of the condition as being satisfied when the value of excess demand in the resale market is positively related to firm G's green effort, i.e., G's excess demand is responsive-enough such that it is consistent with an effort level that satisfies $\phi_2^{G^*} > \tilde{\phi}_2^G$.[29]

4 Conclusions

This paper explores the game-theoretic basis of "green competition", i.e., dueling efforts by firms to enhance their reputations as socially responsible firms, in a Bertrand-equilibrium framework. Using the on-going competition between EV automakers Tesla (e.g., an "aggressive firm") and its competitor bloc ("passive firm"), on the one hand, and outdoor apparel manufacturers Patagonia (aggressive) and The North Face (passive) as our motivation, we have sought answers to two main questions. First, what are the inter-temporal effects of the aggressive firm's strategy on that of the passive firm's, i.e., to what extent should we expect a firm like The North Face (which is facing more aggressive green effort from its competitor Patagonia) to engage in green competition? Second, does the theorized extent of the aggressor's ambition depend upon the choice of equilibrium concept, e.g., when it comes to undertaking its green strategy what effect does the aggressive firm "moving" simultaneously with, as opposed to prior to, the passive firm have on the extent to which the aggressive firm should optimally put forth green effort?

To answer these questions, we first derive three sufficiency conditions that underlie our findings. The first condition (Sufficiency Condition 1) requires that the relative, lagged cross effect of a firm's green effort outweighs its absolute, lagged cross effect, where (1) by "cross effect" we mean, for instance, the effect that the aggressive firm's green effort has on consumer demand for the passive firm's product, (2) by "relative" we mean, for instance, the extent to which the aggressive firm G's lagged (e.g., period 1) green effort tempers the subsequent effects of its contemporaneous (e.g., period 2) green effort on contemporaneous demand for passive firm N's product, and (3) by "absolute" we mean the cross effects associated with G's lagged green effort itself. The second condition (Sufficiency Condition 2) requires that firm G's contemporaneous cross

[29]Note that the inequality for substitutes is automatically satisfied when $\partial \chi_2^u / \partial \phi_2^G < 0$, i.e., when the supply of used product by firm G's consumers is negatively related to G's green-effort level. This is the case when an increase in green effort effectively induces consumers to retain ownership of firm G's product for a longer period of time, thus reducing the need for a resale market to begin with.

effect on firm N's demand also outweighs its lagged absolute cross effect. Finally, the third condition (Sufficiency Condition 3) requires that the firm experiencing the cross effects (e.g., the passive firm) is nevertheless capable of maintaining a sufficiently high price markup and/or sufficiently low marginal costs in the face of the effects. We obtain three main results.

First, we find that the passive firm's inter-temporal, green-effort reaction function is non-monotonic (Proposition 1). In particular, while its best lagged-response to an increase in the aggressive firm's effort is to increase its own effort (e.g., in an attempt to better compete with the aggressive firm on the "green margin"), the passive firm's best concurrent response is to instead decrease its effort (e.g., to withdraw from competing on the green margin). To our knowledge, this is the first instance where a non-monotonic quantity reaction function (for what we are calling green effort) is derived in a differentiated-product, Bertrand-equilibrium setting.

Second, to the extent that the aggressive firm views itself as the leader vis-a-vis the passive firm in building its reputation as the greener firm and to the extent that the indirect effect on its consumer demand of its current green effort (working indirectly through the passive firm's own green effort) outweighs the indirect effect working through the passive firm's pricing strategy, the aggressive firm's optimal second-period effort will be larger than it otherwise would be if it instead viewed itself as choosing its effort simultaneously with the passive firm (Proposition 2). In other words, we are able to characterize the conditions under which the timing of moves on the effort, or quantity, margin in a Bertrand equilibrium induce more or less green effort from the focal firm, i.e., the aggressive firm. Lastly, we introduce a resale market for the aggressive firm's product and derive a necessary and sufficient condition for the establishment of that market to act as a substitute for the aggressive firm's green effort. We show that the condition is met when the value of excess demand in the resale market is positively related to the aggressive firm's green effort (Proposition 3).

Clearly, empirically testing Propositions 1 and 3 with time-series data for aggressive firms such as Tesla and Patagonia and their respective rivals would be a preferable next step in this line of research. The outcome of green competition between firms is of particular interest given Patagonia's bold "Responsible Economy" strategy to reduce its environmental footprint through challenging its consumers to be more responsible with their purchases; a strategy that, in addition to establishing a resale market for its product, involves creating cognitive dissonance in the minds of its consumers regarding their motivations for wanting to purchase new clothing to begin with. The same rings true for Tesla given its bold strategies to create greener transportation systems worldwide with its brand of EV vehicles and associated battery and charging networks.

Regarding Proposition 1, will Patagonia's bloc of rivals respond to its Responsible Economy strategy by retreating from competition on the green margin? Will Tesla's competitor bloc likewise recoil from green competition. Similarly regarding Proposition 3, will the establishment of a resale markets by Tesla and Patagonia for their products ultimately serve as substitutes for what would otherwise be continuation of their green efforts in the future? Generally speaking, answering the first question will indicate the extent to which green effort undertaken by one firm may "crowd out" effort undertaken by its competitors. Answering the second question will likewise indicate the extent to which the establishment of a resale market proverbially "speaks for itself" as a green strategy.

Appendices

A Optimality Conditions

Firms G and N share the following first-order optimality conditions based on maximizing (1) with respect to p_t^i, $i = G,N$, $t = 1,2$, and ϕ_2^i, $i = G,N$, respectively,

$$y_t^i + p_t^i \frac{\partial y_t^i}{\partial p_t^i} - \frac{\partial c^i}{\partial y_t^i} \frac{\partial y_t^i}{\partial p_t^i} = 0 \tag{A.1}$$

$$p_2^i \frac{\partial y_2^i}{\partial \phi_2^i} - \frac{\partial c^i}{\partial y_2^i} \frac{\partial y_2^i}{\partial \phi_t^i} - \frac{\partial c^i}{\partial \phi_2^i} = 0 \tag{A.2}$$

Firm G has an additional optimality condition with respect to its choice of ϕ_1^G,

$$p_1^G \frac{\partial y_1^G}{\partial \phi_1^G} - \frac{\partial c^G}{\partial y_1^G} \frac{\partial y_1^G}{\partial \phi_1^G} - \frac{\partial c^G}{\partial \phi_1^G} + \beta \left(\left[p_2^G - \frac{\partial c^G}{\partial y_2^G} \right] \left[\frac{\partial y_2^G}{\partial \phi_1^G} - \frac{\partial y_2^G}{\partial \Delta^G} \right] \right) = 0. \tag{A.3}$$

Given $\partial y_t^i / \partial p_t^i$, $i = G,N$, $t = 1,2$, (A.1) implies (2) directly. Equation (3) is simply a rewriting of (A.2).

B Existence of an Equilibrium

Recall that the respective spaces of action vis-a-vis green effort for firms G and N are closed and bounded intervals. Therefore, it follows from Heine-Borel Theorem (see Protter and Morrey, 1991) that these spaces of action are compact. In addition, although the price spaces for each firm are the entire real lines, bounded and closed subsets of prices are only relevant due to our assumption that the demand function for each firm is linear in price (i.e, $\partial^2 y_t^i / \partial p_t^i \partial p_t^i = 0$, $i = G, N$, $t = 1, 2$). Letting $\bar{p}^i$, $i = G, N$, represent the respective upper bounds on the closed subsets of prices, we again conclude that price spaces $\left[0,\ \bar{p}^i\right]$, $i = G, N$, are compact. It then follows from Tychonoff's Theorem (see Wilansky, 1983) that $[0,1] \times \left[0, \bar{G}^i\right]$ are compact. Also note that a closed and bounded subset of the real line is convex, hence sets $[0,1] \times \left[0, \bar{p}^i\right]$ are each convex as well. Thus, since the space of strategies in the first period is compact and convex and the payoff functions are continuous and concave, a variant of the Nash Theorem applies to each period (see also Debreu, 1952).

C Proof of Proposition 1

Firm N's system of second-order equations can be written in matrix form as,[30]

$$\begin{bmatrix} A & 0 & 0 \\ 0 & B & C \\ 0 & D & E \end{bmatrix} \begin{bmatrix} dp_1^N \\ dp_2^N \\ d\phi_2^N \end{bmatrix} = \begin{bmatrix} -Fd\phi_1^G \\ -Gd\phi_1^G - Id\phi_2^G \\ -Hd\phi_1^G - Jd\phi_2^G \end{bmatrix} \text{ where,}$$

$$A = 2\frac{\partial y_1^N}{\partial p_1^N} + p_1^N \frac{\partial^2 y_1^N}{\partial p_1^N \partial p_1^N} - \frac{\partial^2 c^N}{\partial y_1^N \partial y_1^N}\left(\frac{\partial y_1^N}{\partial p_1^N}\right)^2 - \frac{\partial c^N}{\partial y_1^N}\frac{\partial^2 y_1^N}{\partial p_1^N \partial p_1^N} < 0 \quad \text{(C.1)}$$

$$B = 2\frac{\partial y_2^N}{\partial p_2^N} + p_2^N \frac{\partial^2 y_2^N}{\partial p_2^N \partial p_2^N} - \frac{\partial^2 c^N}{\partial y_2^N \partial y_2^N}\left(\frac{\partial y_2^N}{\partial p_2^N}\right)^2 - \frac{\partial c^N}{\partial y_2^N}\frac{\partial^2 y_2^N}{\partial p_2^N \partial p_2^N} < 0 \quad \text{(C.2)}$$

$$C = \frac{\partial y_2^N}{\partial \phi_2^N} + p_2^N \frac{\partial^2 y_2^N}{\partial p_2^N \partial \phi_2^N} - \frac{\partial^2 c^N}{\partial y_2^N \partial y_2^N}\frac{\partial y_2^N}{\partial p_2^N}\frac{\partial y_2^N}{\partial \phi_2^N} - \frac{\partial c^N}{\partial y_2^N}\frac{\partial^2 y_2^N}{\partial p_2^N \partial \phi_2^N} > 0 \quad \text{(C.3)}$$

$$D = \frac{\partial y_2^N}{\partial \phi_2^N} + p_2^N \frac{\partial^2 y_2^N}{\partial \phi_2^N \partial p_2^N} - \frac{\partial^2 c^N}{\partial y_2^N \partial y_2^N}\frac{\partial y_2^N}{\partial p_2^N}\frac{\partial y_2^N}{\partial \phi_2^N} - \frac{\partial c^N}{\partial y_2^N}\frac{\partial^2 y_2^N}{\partial \phi_2^N \partial p_2^N} - \frac{\partial^2 c^N}{\partial \phi_2^N \partial y_2^N}\frac{\partial y_2^N}{\partial p_2^N} > 0 \quad \text{(C.4)}$$

$$E = p_2^N \frac{\partial^2 y_2^N}{\partial \phi_2^N \partial \phi_2^N} - \frac{\partial^2 c^N}{\partial y_2^N}\partial y_2^N \left(\frac{\partial y_2^N}{\partial \phi_2^N}\right)^2 - \frac{\partial c^N}{\partial y_2^N}\frac{\partial y_2^N}{\partial \phi_2^N \partial \phi_2^N} - \frac{\partial^2 c^N}{\partial \phi_2^N \partial \phi_2^N} < 0 \quad \text{(C.5)}$$

$$F = \frac{\partial y_1^N}{\partial \phi_1^G} + p_1^N \frac{\partial^2 y_1^N}{\partial p_1^N \partial \phi_1^G} - \frac{\partial^2 c^N}{\partial y_1^N \partial y_1^N}\frac{\partial y_1^N}{\partial p_1^N}\frac{\partial y_1^N}{\partial \phi_1^G} - \frac{\partial c^N}{\partial y_1^N}\frac{\partial^2 y_1^N}{\partial p_1^N \partial \phi_1^G} < 0 \quad \text{(C.6)}$$

$$\begin{aligned} G = \left(\frac{\partial y_2^N}{\partial \phi_1^G} - \frac{\partial y_2^N}{\partial \phi_2^G}\right) + p_2^N \left(\frac{\partial^2 y_2^N}{\partial p_2^N \partial \phi_1^G} - \frac{\partial^2 y_2^N}{\partial p_2^N \partial \Delta^G}\right) - \frac{\partial^2 c^N}{\partial y_2^N \partial y_2^N}\left(\frac{\partial y_2^N}{\partial \phi_1^G} - \frac{\partial y_2^N}{\partial \Delta^G}\right)\frac{\partial y_2^N}{\partial p_2^N} - \quad \text{(C.7)} \\ \frac{\partial c^N}{\partial y_2^N}\left(\frac{\partial^2 y_2^N}{\partial p_2^N \partial \phi_1^G} - \frac{\partial^2 y_2^N}{\partial p_2^N \partial \Delta^G}\right) > 0 \end{aligned}$$

$$\begin{aligned} H = p_2^N \left(\frac{\partial^2 y_2^N}{\partial \phi_2^N \partial \phi_1^G} - \frac{\partial^2 y_2^N}{\partial \phi_2^N \partial \Delta^G}\right) - \frac{\partial^2 c^N}{\partial y_2^N \partial y_2^N}\left(\frac{\partial y_2^N}{\partial \phi_1^G} - \frac{\partial y_2^N}{\partial \Delta^G}\right)\frac{\partial y_2^N}{\partial \phi_2^N} - \frac{\partial^2 c^N}{\partial \phi_2^N \partial y_2^N}\left(\frac{\partial y_2^N}{\partial \phi_1^G} - \frac{\partial y_2^N}{\partial \Delta^G}\right) \quad \text{(C.8)} \\ - \frac{\partial c^N}{\partial y_2^N}\left(\frac{\partial^2 y_2^N}{\partial \phi_2^N \partial \phi_1^G} - \frac{\partial^2 y_2^N}{\partial \phi_2^N \partial \Delta^G}\right) > 0 \end{aligned}$$

$$I = \frac{\partial y_2^N}{\partial \phi_2^G} + p_2^N \frac{\partial^2 y_2^N}{\partial p_2^N \partial \phi_2^G} - \frac{\partial^2 c^N}{\partial y_2^N \partial y_2^N}\frac{\partial y_2^N}{\partial p_2^N}\frac{\partial y_2^N}{\partial \phi_2^G} - \frac{\partial c^N}{\partial y_2^N}\frac{\partial^2 y_2^N}{\partial p_2^N \partial \phi_2^G} < 0 \quad \text{(C.9)}$$

$$J = p_2^N \frac{\partial^2 y_2^N}{\partial \phi_2^N \partial \phi_2^G} - \frac{\partial^2 c^N}{\partial y_2^N \partial y_2^N}\frac{\partial y_2^N}{\partial \phi_2^N}\frac{\partial y_2^N}{\partial \phi_2^G} - \frac{\partial c^N}{\partial y_2^N}\frac{\partial^2 y_2^N}{\partial \phi_2^N \partial \phi_2^G} - \frac{\partial^2 c^N}{\partial \phi_2^N \partial y_2^N}\frac{\partial y_2^N}{\partial \phi_2^G} < 0. \quad \text{(C.10)}$$

[30] Consistent with the analysis presented in Section 2, the right-hand side vector in this equation accounts solely for the comparative-static analysis associated with firm G's choices of effort level in periods one and two, $\phi_1^G$and ϕ_2^G, respectively. Results for the comparative-static analysis associated with firm G's price choices, $p_1^G$and p_2^G are available upon request from the authors.

Moreover, by the sufficient second-order conditions for firm N's profit maximization problem, we have,

$$|\Pi| = \begin{vmatrix} A & 0 & 0 \\ 0 & B & C \\ 0 & D & E \end{vmatrix} < 0$$

Conditions (C.1) and (C.2) follow directly from the curvature conditions on c^N and y_t^N, $t = 1, 2$. Conditions (C.3)–(C.6) and (C.9) follow from these curvature conditions and (2). Condition (C.8) follows from the curvature conditions, (2), and Sufficiency Conditions 1 and 2. Condition (C.10) follows from the curvature conditions, (2), and Sufficiency Condition 3. And finally, condition (C.9) follows from the curvature conditions, (2), and Sufficiency Conditions 1 – 3.

A straight-forward application of Cramer's Rule now results in firm N's full set of reaction functions associated with ϕ_1^G and ϕ_2^G. In particular, we see that,

$$\frac{\partial \phi_2^N}{\partial \phi_1^G} = \frac{A\,[DG - BH]}{|\Pi|} > 0 \tag{C.11}$$

$$\frac{\partial \phi_2^N}{\partial \phi_2^G} = \frac{A\,[DI - BJ]}{|\Pi|} < 0 \tag{C.12}$$

as stated in Proposition 1, and

$$\frac{\partial p_2^N}{\partial \phi_2^G} = \frac{A\,[CJ - IE]}{|\Pi|} < 0 \tag{C.13}$$

which ensures that the first term in Ψ^G is indeed negative.

D Optimality Conditions at the Presence of Used Market

Firm G's set of optimality conditions for (7) include (A.1) for $i = G$, $t = 1$, and

$$\begin{aligned} p_1^G \frac{\partial y_1^G}{\partial \phi_1^G} - \frac{\partial c^G}{\partial y_1^G}\frac{\partial y_1^G}{\partial \phi_1^G} - \frac{\partial c^G}{\partial \phi_1^G} + \beta\left(\left[p_2^G - \frac{\partial c^G}{\partial y_2^G}\right]\left[\frac{\partial y_2^G}{\partial \phi_1^G} - \frac{\partial y_2^G}{\partial \Delta^G}\right]\right) & \\ +\beta\left(v_2^u\left[\frac{\partial x_2^u}{\partial \phi_1^G} - \frac{\partial x_2^u}{\partial \Delta^G}\right] - \gamma_2^u\left[\frac{\partial \chi_2^u}{\partial \phi_1^G} - \frac{\partial \chi_2^u}{\partial \Delta^G}\right]\right) &= 0 \end{aligned} \tag{D.1}$$

$$y_2^G + v_2^u \frac{\partial x_2^u}{\partial p_2^G} + \left(p_2^G - \frac{\partial c^G}{\partial y_2^G}\right)\frac{\partial y_2^G}{\partial p_2^G} - \gamma_2^u \frac{\partial \chi_2^u}{\partial p_2^G} = 0 \tag{D.2}$$

$$x_2^u + v_2^u \frac{\partial x_2^u}{\partial v_2^u} + \left(p_2^G - \frac{\partial c^G}{\partial y_2^G}\right)\frac{\partial y_2^G}{\partial v_2^u} - \gamma_2^u \frac{\partial \chi_2^u}{\partial v_2^u} = 0 \tag{D.3}$$

$$v_2^u \frac{\partial x_2^u}{\partial \phi_2^G} + \left(p_2^G - \frac{\partial c^G}{\partial y_2^G}\right)\frac{\partial y_2^G}{\partial \phi_2^G} - \gamma_2^u \frac{\partial \chi_2^u}{\partial \phi_2^G} - \frac{\partial c^G}{\partial \phi_2^G} = 0 \tag{D.4}$$

$$-\chi_2^u - \gamma_2^u \frac{\partial \chi_2^u}{\partial \gamma_2^u} + \left(p_2^G - \frac{\partial c^G}{\partial y_2^G}\right)\frac{\partial y_2^G}{\partial \gamma_2^u} = 0 \tag{D.5}$$

References

Beladi, H., Liu, L., and Oladi, R (2013), On pollution permits and abatement. *Economics Letters* 119 (3), 302-305.

Beladi, H. and Oladi, R. (2011), Does trade liberalization increase global pollution? *Resource and Energy Economics* 33 (1), 172-178.

B Lab (2016), Using business as a force for good. Retrieved from the internet on Monday, May 2 at https://www.bcorporation.net.

Bulow, J.I., Geanakoplos, J.D., and Klemperer, P.D. (1985b), Multimarket oligopoly: strategic substitutes and complements. *Journal of Political Economy* 93(3), 488-511.

DeBord, M. (2016) That new Tesla probably won't be as cheap as you think. *Business Insider*. Retrieved from the internet on July 18, 2017 at http://www.businessinsider.com/teslas-model-3-strategy-will-keep-price-high-2016-2.

Debreu, G. (1952), A social equilibrium existence theorem. *Proceedings of the National Academy of Sciences* 38(10), 886-893.

Dixit, A.K. (1980) The role of investment in entry-deterrence. *Economic Journal* 90, 95-106.

Fudenberg, D. and Tirole, J. (1984), The fat-cat effect, the puppy-dog ploy, and the lean and hungry look. *The American Economic Review* 74(2), 361-366.

Halla, B. (2015) Piecing together the Tesla strategy puzzle. *Harvard Business Review*. Retrieved from the internet on July 23, 2017 at https://hbr.org/2015/09/piecing-together-the-tesla-strategy-puzzle.

Hoffman, A. (2012), Patagonia: encouraging customers to buy used clothing (A). Case 1-429-230. William Davidson Institute, University of Michigan, Ann Arbor.

Horner, J. (2002) Reputation and competition. *American Economic Review* 92(3), 644-663.

Lee, D. (2017), Cross-border mergers and acquisitions with heterogeneous firms: Technology vs. market motives. *North American Journal of Economics and Finance* 42: 20-37.

Lee, J. and Wong, K-Y. (2005), Vertical integration and strategic trade policies. *North American Journal of Economics and Finance* 16: 93-117.

Mas-Colell, A., Whinston, M.D., and Green J. (1995) *Microeconomic Theory*. New York: Oxford University Press.

Maskin, E. and Tirole, J. (1988), A theory of dynamic oligopoly, II: price competition, kinked demand curves, and edgeworth cycles. *Econometrica* 56(3), 571-599.

McCarthy, N. (2017) Tesla dominates the US electric vehicle market. Forbes. Retrieved from the internet on July 17, 2017 at https://www.forbes.com/sites/niallmccarthy/2017/08/14/tesla-dominates-the-u-s-electric-vehicle-market-infographic/#474eb8bf7be4.

McGinty, M. and F.P. de Vries (2009), Technology diffusion, product differentiation and environmental subsidies. *The BE Journal of Economic Analysis & Policy* 9(1). DOI: https://doi.org/10.2202/1935-1682.2099.

Motta, M. (1993), Endogenous quality choice: price vs. quantity competition. *The Journal of Industrial Economics* 41(2), 113-131.

O'Brien, G. (2012), Patagonia: lessons from a pioneer in responsible business. Business Ethics. Retrieved from the internet on January 27, 2017 at http://business-ethics.com/2012/09/05/1400-patagonia-lessons-from-a-pioneerin-responsible-business/.

O'Dell, J. (2016) What makes a Tesla special? These 10 things, for starters. Nerdwallet, Inc. Retrieved from the internet on June 10, 2017 at https://www.nerdwallet.com/blog/loans/whats-special-tesla-10/.

O'Rourke, D. and Strand, R. (2016), Patagonia: driving sustainable innovation by embracing tensions. Berkeley-Haas Case Series B5853, University of California, Berkeley.

Peters, A. (2027) Patagonia wants to refurbish your old clothes and sell them to someone else. Fast Company. Retrieved from the internet on September 17, 2017 at https://www.fastcompany.com/3067443/patagonia-wants-to-refurbish-your-old-clothes-and-sell-them-to-someone-else.

Protter, M.H. and Morrey, C.B. (1991), A First Course in Real Analysis, New York, Springer-Verlag.

Reinhardt, F., Casadesus-Masanell, R., and Barley, L. (2014), Patagonia (B). Case 9-714-465. Harvard Business School.

Reinhardt, F., Casadesus-Masanell, R., and Kim, H.J. (2010), Patagonia. Case 9-711-020. Harvard Business School.

Ryan, K. (2014) The bottom line: Patagonia, North Face, and the myth of green consumerism. Groundswell. Retrieved from the internet on Saturday, December 27 at http://groundswell.org/the-bottom-line-patagonia-north-face-and-the-myth-of-green-consumerism/.

Sharma, R. (2017) Tesla gaining ground in used car markets. Investopedia. Retrieved from the internet on August 3, 2017 at http://www.investopedia.com/news/tesla-gaining-ground-used-car-markets-tsla-gm/.

Spence, M.A. (1977) Entry, capacity, investment, and oligopolistic pricing. *Bell Journal of Economics* 8, 534-544.

Stevenson, S. (2012) Patagonia's founder is America's most unlikely business guru. Wall Street Journal. Retrieved from the internet on Tuesday, January 27 at http://www.wsj.com/articles/SB10001424052702303513404577352221465986612.

Tai, M-Y., Chao, C-C. , and Hu, S-W. (2015), Pollution, health and economic growth. *North American Journal of Economics and Finance* 32, 155-161.

Voight, J. (2013) Patagonia is taking on a provocative 'anti-growth' position: is it all just a marketing ploy? Adweek. Retrieved from the internet on Thursday, January 29 at http://www.adweek.com/news/advertising-branding/patagonia-taking-provocative-anti-growth-position-152782.

Wilansky, A. (1983). Topology for Analysis.AMC,10, 12.