ONLINE APPENDIX

This Online Appendix to "Toward a Dynamic Notion of Value Creation and Appropriation in Firms: The Concept and Measurement of Economic Gain" is divided into five parts, and provides additional details on the following aspects:

(1) Online Appendix A: This appendix describes some extant notions of static value creation and provides more detailed graphical illustrations of economic gain.
(2) Online Appendix B: This appendix lay out the technical underpinnings of our measurement framework, and includes a simulation analysis.
(3) Online Appendix C: This appendix discusses the issue of competitors innovating simultaneously as the focal firm.
(4) Online Appendix D: This appendix provides some information on data availability.
(5) Online Appendix E: This appendix provides a flow chart to guide implementation of the VCA model.

ONLINE APPENDIX A: STATIC AND DYNAMIC NOTIONS OF VALUE CREATION - GRAPHICAL ILLUSTRATIONS

This appendix describes some extant notions of static value creation and provides more detailed graphical illustrations of economic gain.

Extant Notions of Static Value Creation

As described by the quadrants representing total economic value in table 1, "static" value creation is the amount of economic surplus created by the firm in a given period. We assume that the firm sells its product directly to consumers (i.e., it is positioned at the final stage of a "value chain").[1]

Perfect competition with identical firms

The simplest and most widely discussed notion of value creation among multiple stakeholders arises from price theory in neo-classical economics. The basic version of this theory (perfect competition) assumes an infinite number of identical firms producing a homogenous product (or service) and competing in a market with no entry or exit barriers. Figure A1 provides a simplified representation with two firms.[2] These firms are assumed to purchase inputs from factor markets that are also perfectly competitive. The (marginal) cost curve for a firm, assumed to be flat here, is the sum of what is paid to each of the input providers, e.g., capital owners, employees, management, material suppliers etc. Given the assumption of perfectly competitive factor markets, each input provider *including shareholders* gets paid only their opportunity cost.[3] The demand curve is downward sloping, and provides the maximum quantity of the product that customers are willing to purchase at a given price in a given period. Then, the market price is determined by the intersection of the demand and supply curves.

The total economic value created by *all firms in the industry* is equal to the area between the demand and supply curves. Thus, economic value is created when a firm produces products or services at a cost that is lower than what the consumer is willing to pay

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[1] We consider value that may flow to suppliers but ignore the question of how profit is distributed among firms in a multi-stage value chain or ecosystem. For a recent empirical perspective on this issue, see Dedrick, Kraemer and Linden (2010, 2011).

[2] For the sake of exposition, we assume that only two firms are necessary to fulfill market demand. We also ignore all oligopolistic behavior associated with a small number of firms.

[3] The opportunity cost of a resource for the owner of the resource is the cost of the best alternative foregone by the owner to provide the resource to the firm. However, this may be hard to quantify in practice. For our purposes, the opportunity cost for capital can be considered the market cost of capital for a similar firm. For employees and management, the expected wages outside the firm can be thought of as their opportunity cost. A more nuanced treatment requires that we discriminate between opportunity costs within the industry (i.e., what employees can earn at a firm in the

for that product or service. The amount of value created is equal to the difference between the willingness to pay and the opportunity cost of producing the product (or delivering the service). For instance, the value created by Firm 1 is the shaded area (V_1) below the demand curve, and the value created by Firm 2 is the triangular region marked V_2.[4] Turning to appropriation, the value appropriated by customers, or "consumer surplus", is the difference between what customers are willing to pay for the product and the actual price paid for it. Under the assumptions of perfect competition and identical firms represented in Figure A1, all of the value created is appropriated by the customer. By contrast, the firm and the other input providers obtain no part of the value created.

Perfect competition with non-identical firms

With a simple modification, this notion of value creation can be extended to firms that are not identical, but still face perfectly competitive factor markets. Suppose Firm 1 is more efficient than all the other firms in the market, i.e., it uses a smaller quantity of inputs than other firms to produce the same amount of output (Figure A2). Since the market price is determined by the marginal firm (i.e., Firm 2), it remains at the same level as in Figure A1. However, now for Firm 1, there is a gap between the market price and the total opportunity costs of inputs, which is equal to the additional value created by Firm 1 relative to Firm 2. This surplus beyond the opportunity costs is appropriated by the shareholders of Firm 1, as economic profit or *rent* (shaded box). This conception of value creation forms the basis for most studies of firm performance in the economics, finance and strategy literatures. Also, consistent with this model, corporate finance texts typically assume that the net present value for all stakeholders (other than shareholders) is zero.[5]

Imperfect factor market competition with non-identical firms

One of the limitations of Figure A2 is that it does not clarify how some firms become more efficient than others. It is more likely that the efficiency of Firm 1 resulted from the superior (or luckier) actions of one or more of the stakeholders in the firm, who are likely to command a premium over their opportunity costs. Consistent with this intuition, recent advances in strategic management suggest that stakeholders can and do appropriate some of the rents generated in the value creation process (Asher, Mahoney and Mahoney, 2005; Coff, 1999; Harrison, Bosse and Phillips, 2010). The resource-based view of the firm (Barney, 1991) and works on the dynamics of rent appropriation and stakeholder bargaining power (Castanias and Helfat, 2001; Coff, 1999; Lippman and Rumelt, 2003a, 2003b; Wang and Barney, 2006; Coff, 2010) relax the strong assumption about perfection of the factor markets, and allow for the possibility of stakeholders appropriating beyond what they would enjoy under the perfect market assumptions.

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[4] Firm 1 has been placed to the left of Firm 2; therefore it seems to create a higher amount of value than Firm 2. However, the order of placement is arbitrary, and hence, there is no *ex-ante* difference in the extent of value creation between the two firms.

[5] A zero NPV for a stakeholder implies that no rent is obtained by that stakeholder and, therefore, the stakeholder opportunity costs must be equal to the price paid by the firm for that resource.

Figure A3A presents this conception of value creation and appropriation. The supply curve is still assumed to be at the same level as in Figures A1 and A2, but all the input providers now receive rent beyond their opportunity costs.[6] Though it is not obvious from the figure, we continue to assume that Firm 1 is more efficient. The higher efficiency of Firm 1 implies that the total amount of rent available to all its stakeholders including shareholders is higher than the rent available to Firm 2's stakeholders. To make this clear, Figure A3B presents a simplified view by aggregating the rents. The shaded area within each firm represents the total rent that is available to the firm's stakeholders for appropriation. As can be seen, Firm 1 generates more rent.[7]

Figure A3B also divides the rents into two classes: to shareholders and to other stakeholders (except customers).[8] However, as illustrated in the figure, *this division is entirely arbitrary;* the ultimate division will depend upon stakeholder bargaining power, legal rights and contracts, etc. Though, in general, we would expect a higher total rent to result in greater value appropriation for each stakeholder, it is not necessary. For instance, we can re-draw Figure A3B with all the rent in Firm 1 being appropriated by shareholders with no value received by the other stakeholders. The opposite case with all the value appropriated by other stakeholders (except customers) is also theoretically possible. A harder case to pictorialize is that of Firm 1 passing on some of its efficiency gains to its customers in the form of lower price. In this case, the amount of consumer surplus will increase, and the value appropriated by shareholders and other stakeholders will decrease (assuming no change in quantity).

Stakeholders and Economic Gain: Graphical Illustrations

As discussed in the main text, a firm can create economic gain in two broad ways. Value is created when the size of a superior firm grows more than its competitors (or firms that produce inferior substitutes). To see this graphically, consider Figure A4, where firm 1 (the superior firm) grows at the expense of a less efficient competitor (firm 2). Because firm 1 has a competitive advantage in the first period (left panel), the stakeholders of firm 1 earn rents (lightly shaded rectangles) above their opportunity costs. In the second period, suppose firm 1 grows without any changes in the economic value created per unit. Assuming no change in the overall market size (output), this implies that the total amount of resources used to supply the market demand has decreased. This entire

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[6] In our discussions here, we do not delve into the factors that determine the size and distribution of the rent, such as small numbers bargaining, resource superiority, information asymmetry or other imperfections in the factor markets. Hence, some input providers may receive rents while others do not. Further, the magnitude of the rents for a given input provider may be the same or different across firms. For instance, oil suppliers may receive the same premium from all firms in the industry while management in different firms may receive different levels of rent.

[7] In the diagram, we have shown the marginal firm earning rent. Theoretically, this can only happen if something is limiting competition. For example, a third firm (not shown) earns zero rents, or these firms one and two are limited in their ability to grow rapidly or their input factors (e.g. labor) are colluding (unionizing). Similarly, we assume that capacity constraints or adjustment costs prevent immediate expansion of the more efficient firm.

[8] The limitation to two classes is for maintaining the ease of exposition. Also note that customers continue to receive the same of consumer surplus as the grey shaded area in Figure A1.

additional value created is available to the stakeholders of firm 1 for appropriation (darkly shaded area).

Turning to innovation gain, Figure A5 considers a cost-reducing innovation developed by firm 1 that has resulted in a decrease in the amount of resources used. Since the willingness to pay has not changed, firm 1 has created additional value (darkly shaded box), which is available for appropriation by its stakeholders. Figure A6 presents a stylized picture of value creation and capture from an innovation that increases willingness to pay. (For simplicity, the figure considers only one firm.) Here, we have assumed that the firm did not change prices. Therefore, the value to the firm's internal stakeholders comes from the growth of the firm (shaded vertical rectangle). The additional customer surplus is the shaded trapezium. The economic gain from innovation, then, is the sum of the two shaded areas.

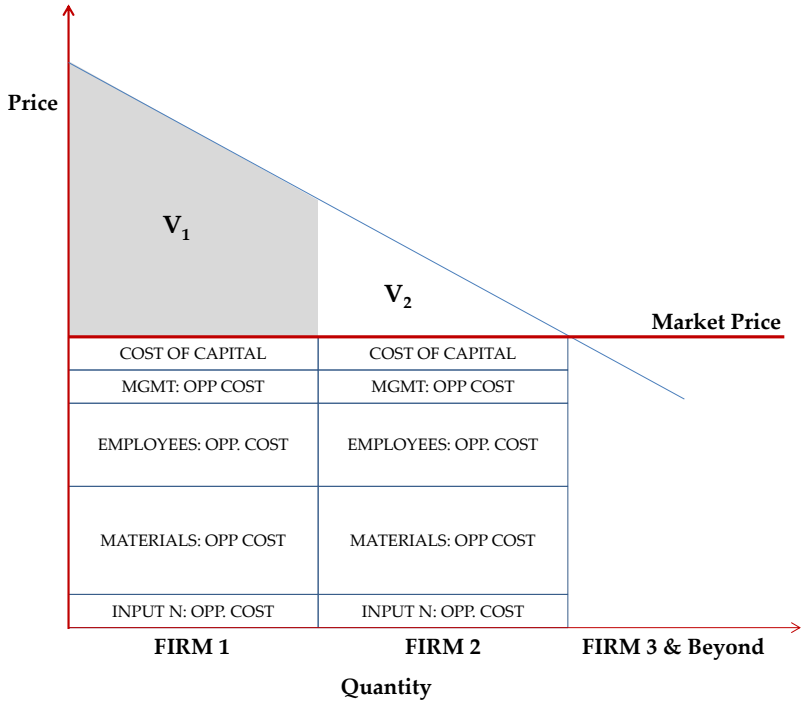


Figure A1: Static value creation by firms in perfect competition

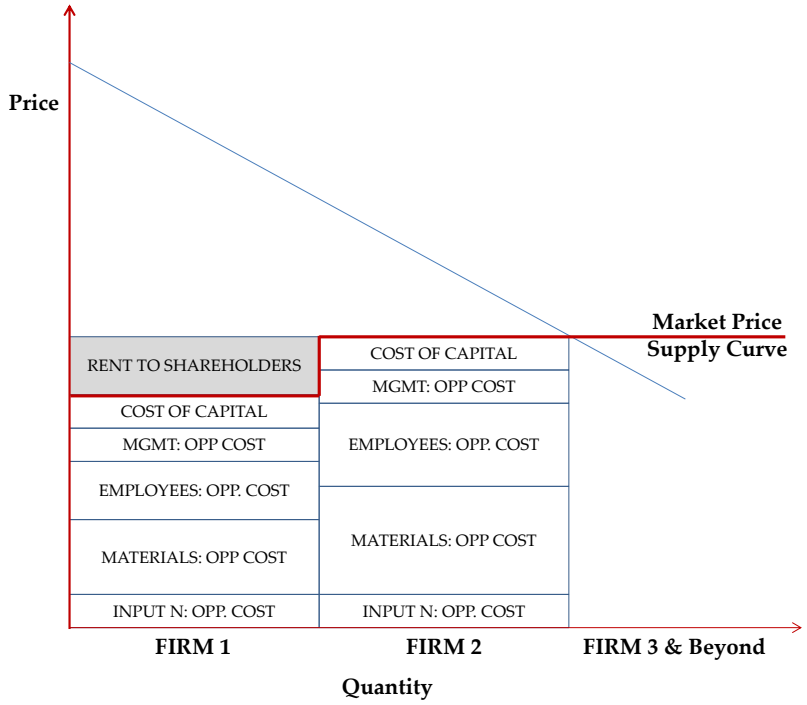
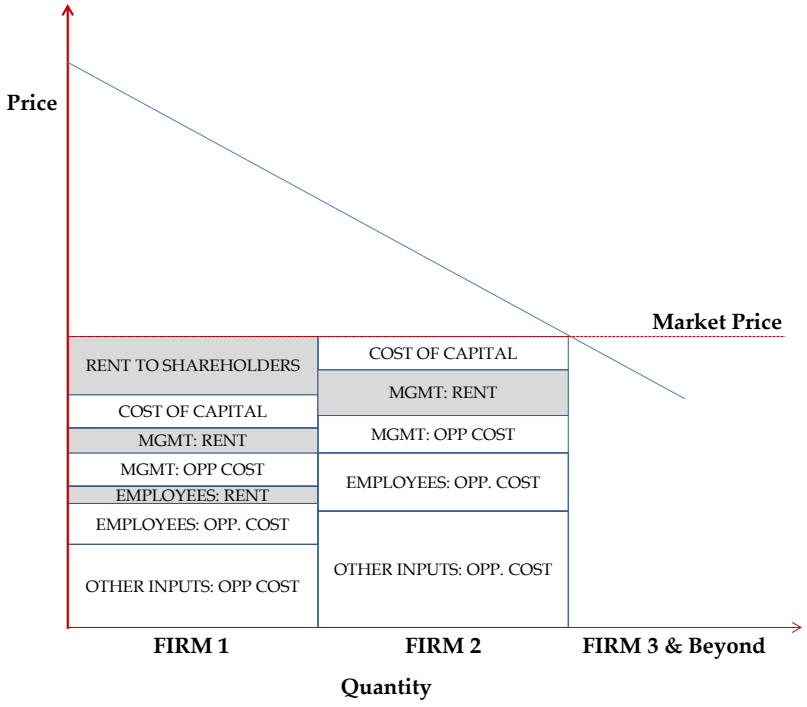
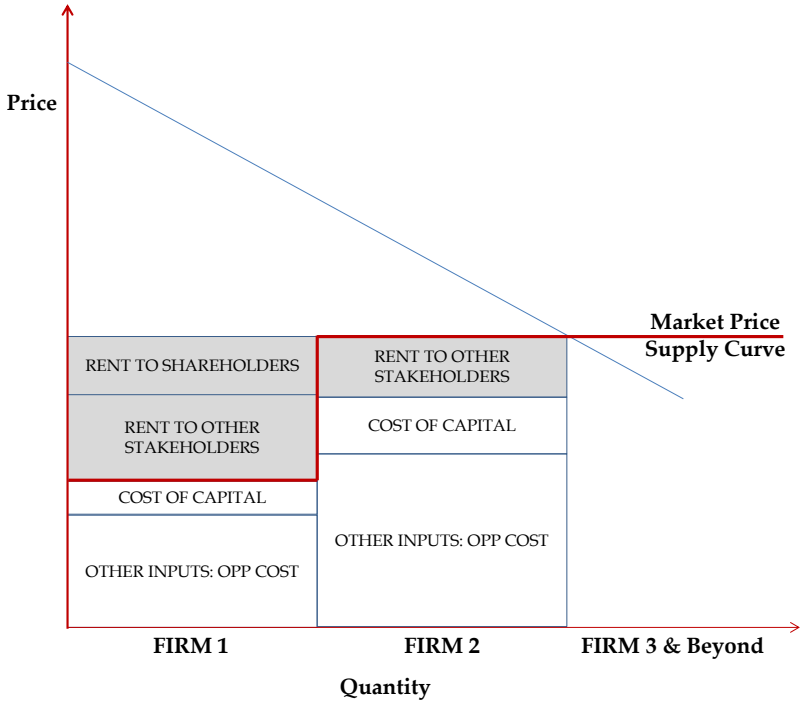


Figure A2: Static value creation by efficient firms with perfect competition in factor markets

Figure A3: Static value creation by efficient firms with imperfect competition in factor markets



(A)



(B)

Figure A4: Economic Gain through Growth of a Superior Firm

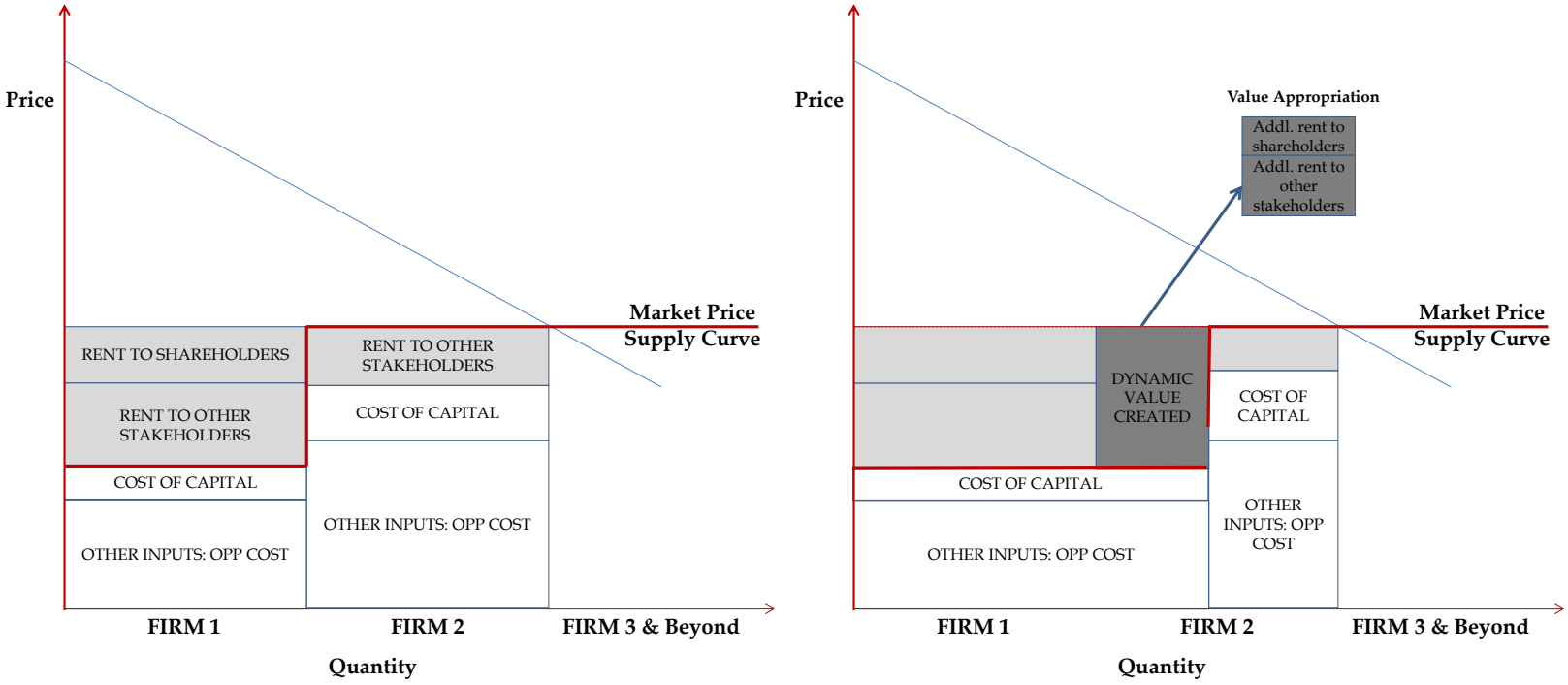


Figure A5: Economic Gain through a Cost-Reducing Innovation

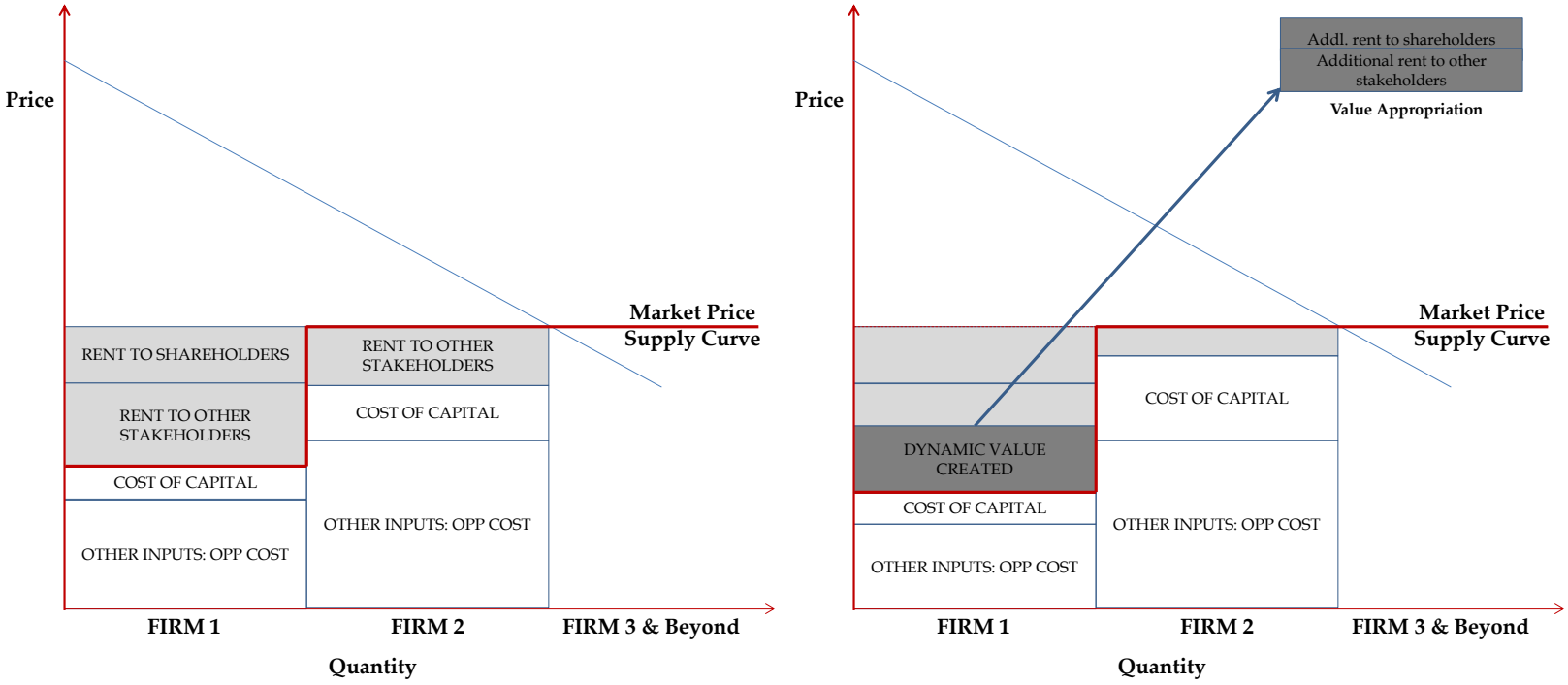
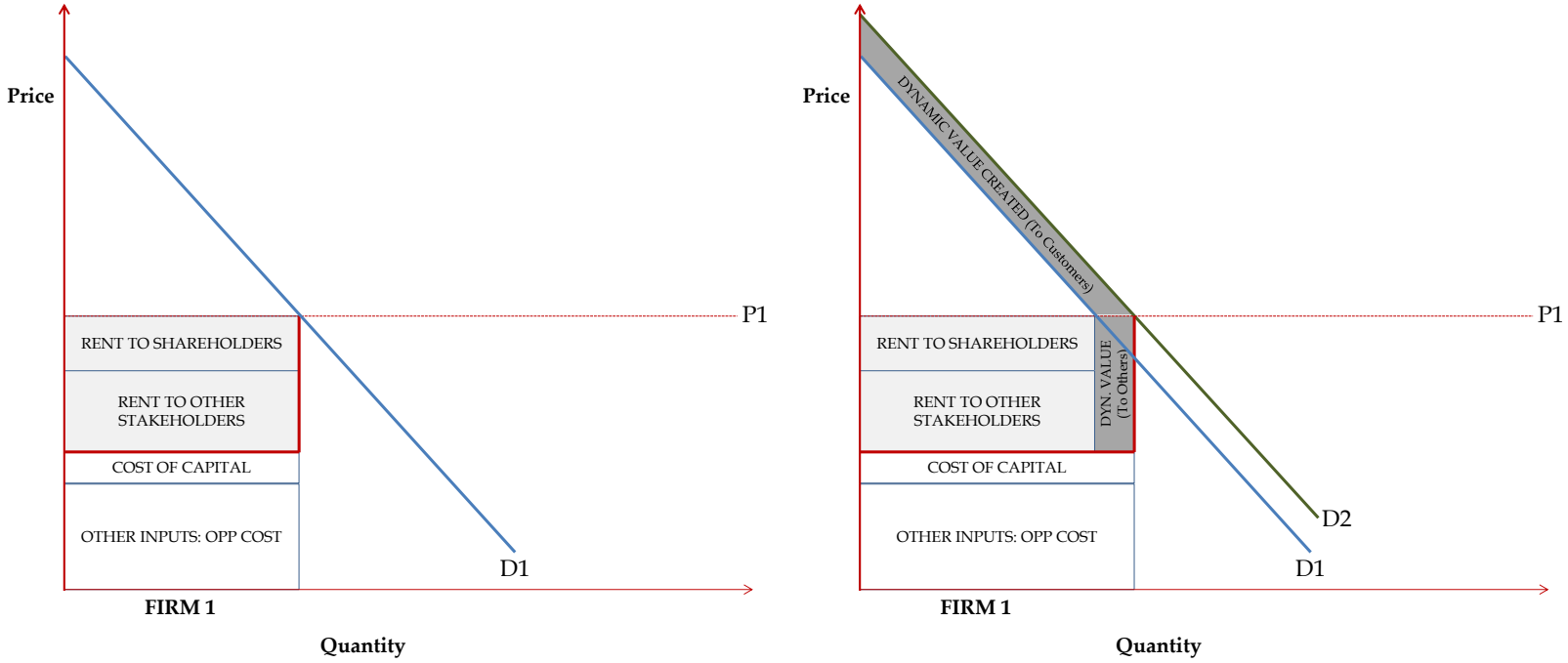


Figure A6: Economic Gain through a WTP-Increasing Innovation



(Period 1) **(Period 2)**

ONLINE APPENDIX B

In this Appendix, we lay out the technical underpinnings of our measurement framework. We do so in two broad ways. The first part provides a series of formal propositions relating to the model while we use a simulation in the second part to complement this formal analysis. As part of our formal analysis, we first prove that under certain assumptions common to the productivity literature, the left hand side of Equation (13) exactly measures the innovation gain defined in Equation (6). We do so in two steps, first keeping willingness-to-pay constant (as assumed in our empirical example) and then allowing it to change. We then prove the right hand side of Equation (13) measures the increase in returns to stakeholders. As last part of the proof, we prove the replication gain formula. We then conclude with a discussion of measurement error that arises when some of the assumptions are relaxed. The simulation focuses on some of the assumptions and attempts to provide a richer understanding of the potential direction and magnitude of impact if these assumptions are not met.

Recall that we use Equation (6) as the theoretical foundation for our measurement:

$$\Gamma_t = \underbrace{\{Y_{t-1}\Delta\nu_t + \Delta\nu_t\Delta Y_t\}}_{\text{“innovation gain”}} + \underbrace{(\nu_{t-1} - \nu_{t-1}^*)\Delta Y_t}_{\text{“replication gain”}} \qquad \text{(B1)}$$

Where Γ_t is economic gain in period *t*, Y_{t-1} is the quality-adjusted (discussed later) output of firm A in period *t-1*, $Y_t = Y_{t-1} + \Delta Y_t$ is the output of firm A in period *t*, ν_{t-1} is the average economic value per unit of firm A in period *t-1*, $\nu_t = \nu_{t-1} + \Delta\nu_t$ is the average economic value per unit of firm A in period *t*, and ν_{t-1}^* is the average economic value per unit of firm A's competitor (or the industry average). For simplicity, we use *t*=1 (first period) and 2 (second period) from now on.

In developing the measurement framework, we assume that the willingness-to-pay per unit of output and the input opportunity costs per unit (of input) are unobservable while the quantity and prices of inputs and outputs are observable.

VCA MODEL

Proposition 1: Consider a firm with cost-reducing innovations which do not affect the willingness-to-pay. Under Assumptions M.1-M.4, the left hand side of Equation (13) is exactly equal to the economic gain from innovation in Equation (6) measured as a percentage of the firm's initial revenues.

Assumption M.1: The firm grows by displacing competitors whose average WTP and average opportunity costs per unit of output are the same as the firm's in the first period.

Assumption M.2: On average, input providers are paid their opportunity cost in the first period.

Assumption M.3: The opportunity cost per unit of inputs is constant over the two periods.

Assumption M.4: The quality of inputs is constant over the two periods.

Comments:

Assumption M.1 would hold true if customers were randomly distributed across firms in the industry (which is likely in many contexts), and if the firm grows at the expense of some competitors. The latter would be true in industries that are not growing rapidly and in cases where firm growth is much larger than industry growth. Assumption M.2 does not require

that all input providers receive their opportunity costs. In particular, it allows for inter-supplier heterogeneity within a class of input providers (e.g., labor providers or capital providers) as long as the input providers on average receive their opportunity costs. This is likely to be the case for many types of input providers, more so if their inputs are commodities in nature. On a related note, Assumption M.3 also implicitly implies that the opportunity cost of any freed-up resources due to the innovation (e.g., labor savings) remain unchanged. If the opportunity cost of the freed-up resources is lower (e.g., if they can only be used partially elsewhere), then the economic gain will be lower. Partial use of the freed-up resources will also affect the equality between value creation and appropriation discussed later. Specifically, the continuing stakeholders of the firm will appropriate more value than they create, with the excess payments drawn from the owners of the freed-up resources. An example of this would be firing some employees (who cannot find a similar-paying job) while simultaneously increasing the wages of workers who continue in the firm.

A deviation from Assumption M.1 is considered in Scenarios 4-6 of the simulation analysis and a digression from Assumption M.2 is considered in Proposition 5 below and in Scenario 2 of the simulation analysis. Proposition 6 describes the measurement error associated with relaxing Assumption M.4.

Proof:

By definition, the economic value created in the first period, ε_1 can be written:

$$\varepsilon_1 = \nu_1.Y_1 + \nu_1.(Y_2-Y_1) = (\omega-o)Y_1 + (\omega-o)\,(Y_2-Y_1) \qquad \text{(B1-1)}$$

where ω is the *average* willingness-to-pay for a unit of output in the first period, and o refers to the average opportunity costs of the inputs. Note that the terms with (Y_2-Y_1) refer to the first period output of competitor that the focal firm will displace in the second period.

We can write the average opportunity cost as:

$$o = (o_L.L_1 + o_K.K_1 + o_M.M_1)/Y_1 \qquad \text{(B1-2)}$$

where the subscripts L, K and M indicate labor, capital and materials, respectively. Substituting this in Equation (B2) above, the right hand side and simplifying, we get,

$$\varepsilon_1 = (\omega - (o_L.L_1 + o_K.K_1 + o_M.M_1)/Y_1)Y_2 \qquad \text{(B1-3)}$$

By Assumption M.1, we can replace the average opportunity costs with the corresponding input prices. So, we can write:

$$\varepsilon_1 = \omega.Y_2 - (wL_1 + rK_1 + mM_1)(Y_2/Y_1) \qquad \text{(B1-4)}$$

Now, writing the average willingness-to-pay as $\omega=p+\sigma$, we get:

$$\varepsilon_1 = pY_2 - (wL_1 + rK_1 + mM_1)(Y_2/Y_1) + \sigma Y_2 \qquad \text{(B1-5)}$$

Turning to the second period, the economic value created in that period is:

$$\varepsilon_2 = \nu_2.Y_2 = \omega.Y_2 - (o_L.L_2 + o_K.K_2 + o_M.M_2) \qquad \text{(B1-6)}$$

which by Assumptions M.3 and M.1 reduces to:

$$\varepsilon_2 = \omega.Y_2 - (wL_2 + rK_2 + mM_2) \qquad \text{(B1-7)}$$

Note that in writing the above, we have also assumed that input quality has remained constant (Assumption M.4). Otherwise, not all of the change in output quantity may be attributable to

change in input quantity; some of the change in output quality may be attributable to the change in input quality.

Since the willingness-to-pay stays constant, the average willingness-to-pay is $\omega=p+\sigma$. So,

$$\varepsilon_2 = pY_2 - (wL_2 + rK_2 + mM_2) + \sigma Y_2 \qquad \text{(B1-8)}$$

Thus, economic gain is:

$$\Gamma = \varepsilon_2 - \varepsilon_1 = (wL_1 + rK_1 + mM_1)(Y_2/Y_1) - (wL_2 + rK_2 + mM_2) \qquad \text{(B1-9a)}$$

$$= wL_1(Y_2/Y_1) - wL_2 + rK_1(Y_2/Y_1) - rK_2 + mM_1(Y_2/Y_1) - mM_2 \qquad \text{(B1-9b)}$$

$$= wL_1(Y_2/Y_1 - L_2/L_1) + rK_1(Y_2/Y_1 - K_2/K_1) + mM_1(Y_2/Y_1 - M_2/M_1) \qquad \text{(B1-9c)}$$

$$= wL_1(\Delta Y/Y_1 - \Delta L/L_1) + rK_1(\Delta Y/Y_1 - \Delta K/K_1) + mM_1(\Delta Y/Y_1 - \Delta M/M_1) \qquad \text{(B1-9d)}$$

where $\Delta Y = Y_2 - Y_1$, $\Delta L = L_2 - L_1$, and so on. Substituting $(wL_1 + rK_1 + mM_1) = pY_1$ by the payment identity, we get

$$\Gamma = pY_1(\Delta Y/Y_1) - wL_1(\Delta L/L_1) - rK_1(\Delta K/K_1) - mM_1(\Delta M/M_1) \qquad \text{(B1-10)}$$

Dividing throughout by the first period revenues (pY_1), and substituting $s_L=(wL_1/pY_1)$, $s_k=(rK_1/pY_1)$, and $s_M=(mM_1/pY_1)$, the right hand side simplifies to:

$$(\Delta Y/Y_1) - s_L(\Delta L/L_1) - s_K(\Delta K/K_1) - s_M(\Delta M/M_1) \qquad \text{(B1-11)}$$

which is equal to the left hand side of Equation (13) in the text.

Proposition 2: Consider a firm with innovations which may affect both unit costs and willingness-to-pay. Then under Axiom 1 and Assumptions M.1-M.6, the left hand side of Equation (13) is exactly equal to the economic gain from innovation in Equation (6) measured as a percentage of the firm's initial revenues.

Axiom 1: Willingness-to-pay equals price for the marginal customer in the first period.

Assumption M.5: There exists a constant-quality price index φ with the following property: $\varphi_2/\varphi_1 = \omega^m{}_2/\omega^m{}_1$, where $\omega^m{}_1$ and $\omega^m{}_2$ are, respectively, the first-period and second-period willingness-to-pay for the first-period marginal customer.

Assumption M.6: The willingness-to-pay for every inframarginal customer, ω^i, follows $\omega^i{}_1 = \omega^m{}_1 + \sigma$ and $\omega^i{}_2 = \omega^m{}_2 + \sigma$.

Comments:

Note that Axiom 1 is the definition of the marginal customer. Broadly, the constant-quality price index (Assumption M.5) measures how much the first-period marginal customer was willing to pay for the second-period quality in the first period. For example, consider a soap manufacturer who priced some soap at $1.00 and which is used at the rate of 1 unit per load of laundry. Then, if it introduces a better quality soap such that each load of laundry requires only 0.9 units of soap, then the customer would be willing to pay $1.11 (1/0.9) for 1 unit of the higher-quality soap. The second-period price index would then be 1.11. Assumption M.6 says that the increase in willingness-to-pay for all customers is equal to the increase in willingness-to-pay for the marginal customer.

A deviation from Assumption M.5 is considered in Scenario 3 of the simulation analysis and in Propositions 7-9 below.

Proof:

The proof largely follows the same outline as for Proposition 1. A key difference is the treatment of output changes. Because quality changes, 1 unit of output in the first period is not the same as 1 unit of output in the second period. So, we define "real output", Y^r, such that

$$Y_1^r=Y_1;\ Y_2^r=Y_2(\varphi_2/\varphi_1) \qquad \text{(B2-1)}$$

and the corresponding change in real output as

$$\Delta Y^r= Y_2^r-Y_1 \qquad \text{(B2-2)}$$

Thus, Y_2^r can be considered as the nominal second period output reweighted for quality differences. For example, in the illustration above, 1 unit of the second period soap would be treated as having a "real output" of 1.11 units, which is consistent with the second-period soap being of higher quality than the first-period soap.

The economic gain created in the second period is:

$$\Gamma= (\omega_2-o_2)Y_2-(\omega_1-o_1)Y_1-(\omega_1-o_1)\ (Y_2-Y_1) \qquad \text{(B2-3a)}$$

$$= (\omega_2-\ \omega_1)Y_2 - (o_2-o_1)Y_2 \qquad \text{(B2-3b)}$$

Where ω is the *average* willingness-to-pay for a unit of output, and o refers to the average opportunity costs of the inputs, and the subscripts refer to the two periods. As in Proposition 1, the term with (Y_2-Y_1) refers to the first period output of competitor that the focal firm displaces in the second period.

Consider $(\omega_2-\ \omega_1)Y_2$ first. By Assumption M.6, we can write:

$$(\omega_2-\ \omega_1)Y_2 = (\omega^m_2-\ \omega^m_1)Y_2 \qquad \text{(B2-4a)}$$

$$= (\omega^m_2/\ \omega^m_1-1)Y_2 \qquad \text{(B2-4b)}$$

By Axiom 1, $\omega^m_1=p$. Also, by Assumption M.5, $\varphi_2/\varphi_1 = \omega^m_2/\omega^m_1$. Thus, (B2-4) simplifies to:

$$(\omega_2-\ \omega_1)Y_2 = pY_2\ (\varphi_2/\varphi_1-1) \qquad \text{(B2-5)}$$

Substituting $Y_2^r = Y_2(\varphi_2/\varphi_1)$, we get from reduces to:

$$(\omega_2-\ \omega_1)Y_2 = p(Y_2^r-Y_2) \qquad \text{(B2-6)}$$

Now consider $-(o_2-o_1)Y_2$. Substituting $o_2=(wL_2+rK_2+mM_2)/Y_2$ and $o_1=(wL_1+rK_1+mM_1)/Y_1$,

$$-(o_2-o_1)Y_2 = (wL_2+rK_2+mM_2)-(wL_1+rK_1+mM_1)(Y_2/Y_1) \qquad \text{(B2-7a)}$$

$$= wL_1(Y_2/Y_1) - wL_2 + rK_1(Y_2/Y_1) - rK_2\ + mM_1(Y_2/Y_1) - mM_2 \qquad \text{(B2-7b)}$$

$$= wL_1(Y_2/Y_1- L_2/L_1) + rK_1(Y_2/Y_1- K_2/K_1) + mM_1(Y_2/Y_1- M_2/M_1) \qquad \text{(B2-7c)}$$

$$= wL_1(\Delta Y/Y_1- \Delta L/L_1) + rK_1(\Delta Y/Y_1- \Delta K/K_1) + mM_1(\Delta Y/Y_1- \Delta M/M_1) \qquad \text{(B2-7d)}$$

where $\Delta Y= Y_2- Y_1$, $\Delta L= L_2- L_1$, and so on. Substituting $(wL_1+ rK_1+ mM_1) = pY_1$ we get:

$$-(o_2-o_1)Y_2 = pY_1(\Delta Y/Y_1) - wL_1(\Delta L/L_1) - rK_1(\Delta K/K_1) - mM_1(\Delta M/M_1) \qquad \text{(B2-8)}$$

Thus, the true economic gain (Equation B2-3) becomes:

$$\Gamma = (\omega_2-\ \omega_1)Y_2 - (o_2-o_1)Y_2 \qquad \text{(B2-9a)}$$

$$= p(Y_2^r-Y_2) + pY_1(\Delta Y/Y_1) - wL_1(\Delta L/L_1) - rK_1(\Delta K/K_1) - mM_1(\Delta M/M_1) \qquad \text{(B2-9b)}$$

$$= p(Y_2^r - Y_1) - wL_1(\Delta L/L_1) - rK_1(\Delta K/K_1) - mM_1(\Delta M/M_1) \quad \text{(B2-9c)}$$

$$= p\Delta Y^r - wL_1(\Delta L/L_1) - rK_1(\Delta K/K_1) - mM_1(\Delta M/M_1) \quad \text{(B2-9d)}$$

Dividing throughout by the first period revenues (pY_1), and substituting $s_L=(wL_1/pY_1)$, $s_k=(rK_1/pY_1)$, and $s_M=(mM_1/pY_1)$, the right hand side simplifies to:

$$(\Delta Y^r/Y_1) - s_L(\Delta L/L_1) - s_K(\Delta K/K_1) - s_M(\Delta M/M_1) \quad \text{(B2-10)}$$

which is equal to the left hand side of Equation (13) in the text.

Proposition 3a: Consider the economic gain captured by the input providers. If Axiom 1 and Assumptions M.1-M.6 hold, then the economic gain from innovation (measured as percentage of the initial period revenues) captured by customers, providers of labor, capital and materials are, respectively, $-g_Y^r(\Delta p^r/p)$, $g_L s_L(\Delta w/w)$, $g_k s_k(\Delta r/r)$ *and* $g_m s_m(\Delta m/m)$, *where* Δp^r *is the change in real price and equals* $(p_2^r - p_1)$, $\Delta w=w_2-w_1$, $\Delta r=r_2-r_1$ *and* $\Delta m=m_2-m_1$, g_Y^r, g_L, g_K, *and* g_M *are the growth in real output, labor, capital and materials respectively.*

Proposition 3b: Consider the increase in unit returns to the input providers. If Axiom 1 and Assumptions M.1-M.7 hold, then the increase in unit returns associated with the economic gain from innovation (measured as percentage of the initial period revenues) are given by the right hand side of Equation (13) in the text. Specifically, the increase in unit returns for customers, providers of labor, capital and materials are, respectively, $-(\Delta p^r/p)$, $s_L(\Delta w/w)$, $s_k(\Delta r/r)$ *and* $s_m(\Delta m/m)$.

> *Assumption M.7: The changes* Δp^r, ΔY,... ΔM *are small relative to their corresponding initial values so that the cross products* $\Delta p\Delta Y$, $\Delta w\Delta L$ *etc. can be ignored.*

Comments:

Real price is defined analogously to real output. Broadly, the real price is what the current period price is equal to when adjusted for quality changes from the prior period. In the example of a soap manufacturer above, suppose the first period price is \$1.00 and the second period price is \$1.05. Then, the real price in the second period is lower than \$1.05 because the quality of the soap has increased. In particular, the customer is willing to pay \$1.11 for 1 unit of the higher-quality soap. Hence, the real price would be (1.05/1.11=0.95). So, adjusted for quality changes, the real price of soap has actually declined.

Proof:

First, note that real price in the second period is $p_2^r = p_2(\varphi_1/\varphi_2)$. Hence, $p_2^r Y_2^r = p_2 Y_2$.

Consider the change in consumer surplus associated with the economic gain, which is the sum of the increase in consumer surplus for the first period customers (or output) and the increase in consumer surplus for the new customers in the second period. :

$$\Delta CS = (\omega_2 - p_2)Y_1 + (\omega_2 - p_2)(Y_2 - Y_1) - (\omega_1 - p_1)Y_1 - (\omega_1 - p_1)(Y_2 - Y_1) \quad \text{(B3-1a)}$$

$$= (\omega_2 - p_2)Y_2 + (\omega_1 - p_1)Y_2 \quad \text{(B3-1b)}$$

$$= (\omega_2 - \omega_2)Y_2 + (p_2 - p_1)Y_2 \quad \text{(B3-1b)}$$

By Assumption M.6 and since $\omega^m_1 = p_1$, we can write:

$$\Delta CS = (\omega^m_2 - \omega^m_1)Y_2 + (p_2 - p_1)Y_2 \quad \text{(B3-2a)}$$

$= (\omega^m_2 - p_2)Y_2$ (B3-2b)

By Axiom 1, $\omega^m_1 = p_1$. By Assumption M.5, $\varphi_2/\varphi_1 = \omega^m_2/\omega^m_1$. Also, $Y_2^r = Y_2(\varphi_2/\varphi_1)$. Thus, (B3-2b) can be rewritten as:

$\Delta CS = (\omega^m_2 - p_2)Y_2^r(\omega^m_2/p_1)$ (B3-2b)

Dividing both sides by p_1Y_1, we get the change in consumer surplus as a percentage of initial revenues:

$\Delta CS/ p_1Y_1 = (\omega^m_2 - p_2)Y_2^r(p_1/\omega^m_2)(1/ p_1Y_1)$ (B3-3a)

$= (1-p_2/ \omega^m_2)(Y_2^r/Y_1)$ (B3-3b)

$= (1-p_{2r}/p_1)(Y_2^r/Y_1)$ (B3-3c)

since $p_2^r = p_2(\varphi_1/\varphi_2)$ and $\varphi_2/\varphi_1 = \omega^m_2/\omega^m_1$, which implies $(p_2/\omega^m_2)=(p_2/p_1)$

$= - g_Y^r(\Delta p^r/p_1)$ where$\Delta p^r = (p_2^r - p_1)$ and $g_Y^r=(Y_2^r/Y_1)$ (B3-3d)

This proves the consumer-related part of Proposition 3a. To see the labor-related gains, note that the change in total wages for labor are:

Δtotal wage $= (w_2 - w_1)L_1 + (w_2 - w_1)(L_2-L_1)$ (B3-4a)

$= (w_2 - w_1)L_2$ (B3-4b)

$= (w_2 - w_1)g_LL_1$ where $g_L=L_2/L_1$ (B3-4c)

Dividing both sides by p_1Y_1, we get the change in wages as a percentage of initial revenues:

Δtotal wage$/ p_1Y_1 = (w_2 - w_1)g_LL_1(1/ p_1Y_1)$ (B3-5a)

$= g_Ls_L(\Delta w/w_1)$ where $s_L= w_1L_1/ p_1Y_1$ (B3-5b)

The proof for capital and material providers follow analogously to the labor gains proof above.

To prove Proposition 3B, note that under Assumption M.7, we can replace g_Y^r, g_L, g_K, and g_M with 1 in the above expressions. To see this, consider the expression for labor gains $g_Ls_L(\Delta w/w_1)$. This can be written as $(1+\Delta L/L_1)s_L(\Delta w/w_1) = s_L(\Delta w/w_1) + s_L(\Delta w/w_1)(\Delta L/L_1)$, which reduces to $s_L(\Delta w/w_1)$. The expressions for the other input providers follow similarly.

Proposition 4: Suppose there exists a competitor that pays its input owners their opportunity costs and with the same WTP as the focal firm. Let Y_c, L_c, K_c and M_c be the competitor's quantities, p_c, w_c, r_c and m_c be the prices, and ρ a scaling factor such that $Y_c=\rho Y_1$, where Y is the output of the focal firm. Let $G_M = -s_{Lc}(\Delta L_c/L_c) + s_{Kc}(\Delta K_c/Kc) + s_{Mc}(\Delta M_c/M_c)$ where $\Delta Z_c=(\rho Z_1 - Z_c)$, Z={L, K, M}, and $s_{Lc} = (w_cL_c/p_cY_c)$, $s_{Kc} = (r_cK_c/p_cY_c)$, and $s_{Mc} = (m_cM_c/p_cY_c)$. Then, $(1/\rho)p_cY_cG_M(Y_2-Y_1)/Y_1$ is equal to replication gain as defined in Equation (6).

Proof:

The proof follows the same arguments as in Propositions 1 and 2. In particular, p_c, w_c, r_c and m_c are the willingness-to-pay for the marginal customer and opportunity costs for the input providers. Hence, the true economic value created by the focal firm in the first period is:

$p_cY_1 - w_cL_1 - r_cK_1 - m_cM_1$. (B4-1)

Now, the left hand side of Equation 12 (or G_M above) multiplied by p_cY_c gives us:

$$(-w_cL_1 - r_cK_1 - m_cM_1) + (1/\rho)(w_cL_c + r_cK_c + m_cM_c) \quad \text{(B4-2a)}$$

$$= (-w_cL_1 - r_cK_1 - m_cM_1) + (1/\rho)p_cY_c \quad \text{(B4-2b)}$$

since the competitor pays its input owners their opportunity costs

$$= (-w_cL_1 - r_cK_1 - m_cM_1) + p_cY_1 \quad \text{(B4-2c)}$$

Simplifying, we get $p_cY_1 - w_cL_1 - r_cK_1 - m_cM_1$, which equals (B4-1). Dividing by Y_1 gives the additional economic value created per unit in the first period by the firm, and multiplying by (Y_2-Y_1) gives the replication gain.

MEASURMENT ERROR

Now we briefly discuss some sources of measurement error that may arise in our framework. For parsimony, we focus only on innovation gain. As we did when developing the measurement framework, we assume that the willingness-to-pay per unit of output and the input opportunity costs per unit (of input) are unobservable while the quantity and prices of inputs and outputs are observable.

Error: On average, input providers are not paid their opportunity costs (Assumption M.2 does not hold)

Proposition 5. Consider some input, say labor, which is not paid its opportunity cost in the first period. In particular, let $w_1=o_L + \psi$ for labor, where w is the wage in the first period, o_L is the opportunity cost and is ψ the surplus (or deficit) over the opportunity costs. Then, ceteris paribus, the magnitude of the measurement error is increasing in ψ. Also,

- *(i) The left hand side of Equation (13) overestimates true innovation gain if (a) $\psi>0$ and the firm uses less labor in the next period (b) $\psi<0$ and the firm uses more labor in the next period*
- *(ii) The left hand side of Equation (13) underestimates true innovation gain if (a) $\psi>0$ and the firm uses more labor in the next period (b) $\psi<0$ and the firm uses less labor in the next period*

Proof:

Since all other things remain unchanged, the true economic gain is given by the opportunity cost of labor multiplied by the change in labor quantity. That is

$$\Gamma = -o_L(L_2 - L_1) \quad \text{(B5-1)}$$

The measured economic gain using Equation (13) is

$$G = -(pY_1)s_L(L_2 - L_1)/L_1 \quad \text{(B5-2a)}$$

$$= -w(L_2 - L_1) \quad \text{(B5-2b)}$$

$$= -(o_L + \psi)(L_2 - L_1) \quad \text{(B5-2c)}$$

Then, the measurement error is given by:

$$\text{Measurement error} = \Gamma - G \quad \text{(B5-3a)}$$

$$= -\psi(L_2 - L_1) \quad \text{(B5-3b)}$$

Hence, the magnitude of the measurement error is increasing in ψ. Also if the firm uses less of an input $(L_2 - L_1)<0$ that earns a rent in the first period ($\psi>0$), then the framework overestimates the true economic gain. The other implications follow similarly.

Error: There are changes in input quality from one period to the next. (Assumption M.4 does not hold)

Proposition 6. Consider a change in quality of some input, say labor, over the first period. In particular, let the quality change be such that a unit of labor in the second period is equivalent to z units of labor in the first period. Then, if z>1 and the quality change is not corrected for, (i) the measured innovation gain will overestimate the true economic gain (ii) the measured gains captured by labor will overestimate the true gains captured by labor (iii) the extent of error in both (i) and (ii) is increasing in z.

Proof:

Define "real labor" in the second period L_2^r as $L_2^r=zL_2$. Thus, if z>1, then labor in the second period is of higher quality than labor in the first period (e.g., more skilled). Correspondingly, define "real wage" in the second period as $w_2^r=w_2/z$. Hence, this measures the second-period wages for a unit of labor with first-period quality.

Since all other things remain unchanged, the true economic gain is given by the opportunity cost of real labor multiplied by the change in labor quantity. That is

$$\Gamma = - w_1(L_2^r-L_1) \quad \text{(B6-1)}$$

The measured economic gain, if not corrected for the quality change, is

$$G = - w_1(L_2-L_1) \quad \text{(B6-2)}$$

The measurement error, therefore is,

$$\text{Measurement error} = \Gamma - G \quad \text{(B6-3a)}$$
$$= w_1(L_2^r- L_2) \quad \text{(B6-3b)}$$
$$= w_1L_2(z-1) \quad \text{(B6-3c)}$$

Hence, the magnitude of the measurement error is increasing in *z*. Also if z>1, the measured innovation gain will overestimate the true economic gain.

To prove (ii), the true gains captured by labor are:

$$L_1(w_2^r-w_1) + (L_2^r-L_1)(w_2^r-w_1) \quad \text{(B6-4a)}$$
$$= (w_2^r-w_1)L_2^r = (w_2/z-w_1)(zL_2) = (w_2- zw_1L_2) \quad \text{(B6-4b)}$$

The measured gains captured by labor, not assuming changes are small, is:

$$(w_2- w_1L_2) \quad \text{(B6-5)}$$

Thus, the measurement error is

$$(z-1)\, zw_1L_2 \quad \text{(B6-6)}$$

Hence, the magnitude of the measurement error is increasing in *z*. Also if z>1, the measured gain captured by labor will overestimate the true economic gain captured by labor. A similar result holds for unit wages.

Intuitively, thus, not being able to correct for input quality increases will result in a spurious economic gain and a spurious capture of that gain by the input provider. A constant-quality input price index can proxy for *z* above, and address this concern.

Error: There are changes in output quality from one period to the next and no constant-quality price index of the form in Assumption M.5 is available. (Assumption M.5 does not hold)

The intuition described above for Proposition 6 holds in its entirety, albeit with the opposite sign for uncorrected output quality changes. So, we state the following proposition without proof.

Proposition 7. Consider a change in the quality of output over the first period. In particular, let the quality change be such that the first-period marginal customer's willingness-to-pay for the second-period output be ω^m_2 and ω^m_1 be that customer's first-period willingness-to-pay for the first-period output. Then, if $\acute{z}=\omega^m_2/\omega^m_1>1$ and the quality change is not corrected for, (i) the measured innovation gain will underestimate the true economic gain (ii) the measured gains captured by the consumer will underestimate the true gains captured by consumer (iii) the extent of error in both (i) and (ii) is increasing in $\acute{z}$.

Error: Only an industry-level constant quality price index is available, and there is inter-firm heterogeneity in quality changes. (Assumption M.5 holds only partially).

Proposition 8. Consider a change in the quality of a firm's output over the first period. In particular, let the quality change be such that the first-period marginal customer's willingness-to-pay for the second-period output be ω^m_2 and ω^m_1 be that customer's first-period willingness-to-pay for the first-period output. Suppose the available industry-level constant quality price index, φ^{ind} is such that $\dot{z}(\varphi^{ind}_2/\varphi^{ind}_1)= (\omega^m_2/\omega^m_1)$. Then,

- *(a) if $\dot{z}>1$ and $(\omega^m_2/\omega^m_1)>1$ (i) the measured innovation gain will underestimate the true economic gain (ii) the measured gains captured by the consumer will underestimate the true gains captured by consumer (iii) the extent of error in both (i) and (ii) is increasing in z.*
- *(b) if $\dot{z}=1$ there is no measurement error.*
- *(c) if $\dot{z}<1$ and $(\omega^m_2/\omega^m_1)>1$ (i) the measured innovation gain will overestimate the true economic gain (ii) the measured gains captured by the consumer will overestimate the true gains captured by consumer (iii) the extent of error in both (i) and (ii) is increasing in z.*

The intuition described above for Proposition 6 largely holds, albeit with the opposite sign for uncorrected output quality changes. First of all, note that Proposition 7 is a special case of Proposition 8 with $\dot{z}=0$, where there is no correction for output quality changes. Note that if $\dot{z}>1$, then the firm makes higher quality improvements than the industry. Thus, we will underestimate the increase in real output, and consequently underestimate the true economic gain. Similarly, we will overestimate the increase in real price and underestimate the true economic gains captured by consumers.

Error: Only revenue data are available. Unit output price and output quantity data are not available. An industry-level constant-quality price index is used to proxy for price changes.

Our maintained assumption thus far, has been that both price and quantity data are available. However, it is possible that only revenue data are available. In such cases, a reasonable alternative is to use an industry-level constant-quality price index to proxy for price changes.

Proposition 9. Consider a change in the quality of a firm's output over the first period. In particular, let the quality change be such that the first-period marginal customer's willingness-to-pay for the second-period output be ω^m_2 and ω^m_1 be that customer's first-period willingness-to-pay for the first-period output. Suppose the industry-level constant quality price index, φ^{ind} is such that $\dot{z}(\varphi^{ind}_2/\varphi^{ind}_1)= (\omega^m_2/\omega^m_1)$. If "deflated output", $Y^O=(pY\varphi^{ind})$, is used to proxy for firm output Y and "deflated price" $p^O=(1/\varphi^{ind})$, is used to proxy for firm prices, then:

- *(a) if $\dot{z} > p_2/p_1$ and $(\omega^m_2/\omega^m_1)>1$ (i) the measured innovation gain will underestimate the true economic gain (ii) the measured gains captured by the consumer will underestimate the true gains captured by consumer (iii) the extent of error is a function of $\dot{z}$ and the prices*
- *(b) if $\dot{z} = p_2/p_1$ there is no measurement error*
- *(c) if $\dot{z} < p_2/p_1$ and $(\omega^m_2/\omega^m_1)>1$ (i) the measured innovation gain will overestimate the true economic gain (ii) the measured gains captured by the consumer will overestimate the true gains captured by consumer (iii) the extent of error is a function of $\dot{z}$ and the prices*

Proof:

From Proposition 2, the true economic gain as a percentage of initial revenues is given by:

$$\Gamma/p_1Y_1 = (\Delta Y^r/Y_1) \quad \text{(B9-1a)}$$

$$= (Y_2\omega^m_2/\ \omega^m_1 - Y_1)\ /Y_1 = (\omega^m_2Y_2/\omega^m_1Y_1)-1 \quad \text{(B9-1b)}$$

The measured economic gain is given by the percentage change in deflated output, which is:

$$G/p_1Y_1 = (Y^O_2 - Y^O_1)/\ Y^O_1 = (p_2Y_2\varphi^{ind}_2)/\ (p_1Y_1\varphi^{ind}_1) -1 \quad \text{(B9-2)}$$

Then, the measurement error is given by

$$\Gamma - G = (p_1Y_1)\big(\ (p_2Y_2\varphi^{ind}_2)/\ (p_1Y_1\varphi^{ind}_1)- (\omega^m_2Y_2/\omega^m_1Y_1)\big) \quad \text{(B9-3a)}$$

$$= (p_1Y_1)(Y_2/Y_1)\big(\ (p_2\varphi^{ind}_2)/\ (p_1\varphi^{ind}_1)- (\omega^m_2/\omega^m_1)\big) \quad \text{(B9-3b)}$$

$$= (p_1Y_1)(Y_2/Y_1)\ (\omega^m_2/\omega^m_1)(p_2/\ \dot{z}p_1- 1) \quad \text{(B9-3c)}$$

Thus, if $\dot{z} < p_2/p_1$, the last term is positive and the model overestimates true economic gain. On the other hand, if $\dot{z} < p_2/p_1$ the model underestimates true economic gain.

Thus, in the absence of quantity and price information, an addition assumption that the price changes by the firm reflect the quality changes in the output is required. Intuitively, the absence of quantity and price information makes it impossible to disentangle changes in price due to quality changes and changes in price because of the firm seeking to extract more of the consumer surplus for itself.

SIMULATION ANALYSIS

We complement the above formal analysis with a simulation analysis. Among others, it sheds light on how demand elasticities may interact with the framework. For parsimony, we limit to innovation gain. In particular, this analysis shows the conditions under which the VCA model measures the actual innovation gains without any error, and examines the magnitude of errors associated with various deviations from those conditions. In particular, we focus on three sources of errors (i) deviation from opportunity costs in the initial period (ii) errors in quality adjustment (iii) adding extra-marginal customers. Broadly, we find that a premium paid to

input owners over opportunity costs results in a proportionate overestimation of economic gain while underestimating quality changes results in a proportionate underestimation of economic gain. Adding extra-marginal customers overestimates economic gain but the extent of overestimation is likely to be small except possibly in industries with very high demand elasticities.

Simulation Setup

We considered a firm in an industry facing an isoelastic demand curve of the form $p=10q^{-\varepsilon}$ for our analysis.[9] We considered three levels of elasticity in range with elasticities found in real life: -0.33 (low), -0.67(moderate) and -1.50 (high). Industry output for any given period was computed using the demand curve and the industry price during that period. Producing each unit of output was assumed to require θ units of labor and 1 unit of capital. The opportunity costs for labor and capital were set to $\frac{1}{8}$ throughout. We studied the effect of innovations for two levels of industry innovation (or spillovers) under each of six different scenarios using 1000 simulated firms in each case.

Innovation

In period 1, θ was assumed to be 1. In period 2, θ was randomly reduced by a factor ρ, which was uniformly distributed between 0 and 0.50. Innovation size was measured by this factor. Thus, larger innovations reduced the unit cost more than smaller innovations.

Growth

In period 1, firm 1 was assumed to be 5% of the industry.[10] In period 2, firm output was assumed to grow in two ways. First, the firm could grow by capturing existing customers of its competitors. Since these customers are already in the industry, by definition, their willingness-to-pay is at least equal to the industry price. We allowed this growth to range from 0% to 100% of initial period output. Second, the firm could grow by adding customers new to the industry. This term is set to zero in the Baseline scenario, in line with our assumption.

Model measurement error

This was computed as (innovation gain using the VCA model minus actual innovation gain) divided by the actual innovation gain. Hence, a positive number indicates overestimation and a negative number indicates underestimation.

Scenario 1: Baseline

This scenario was used to show that under the assumptions discussed in the text, the measurement framework measures the actual innovation gains without any error. In line with the assumptions, we assumed that (i) factors are paid their opportunity costs and that (ii) the firm does not add extra-marginal customers in the second period. We then compute the actual innovation gain, the measured innovation gain from Equation (10) and the measurement error. The results are presented in Row 1of Figure B1. As can be seen, Equation (10) estimates the actual innovation gains without any error (Column 1 of Figure B1). This result is also independent of the size of the innovation and the growth of the firm from capturing competitors' customers (Column 2 of Figure B1).

[9] We also tested our simulation with a linear demand curve and obtained similar inferences.
[10] We also tested our simulation with initial market shares ranging from 2-20% and found similar inferences.

Scenario 2: Wage premium in period 1

This scenario was used to study the impact of a factor being paid more than their opportunity cost in the initial period. In particular, we assumed that labor is paid a 10% premium in period 1.

The results are presented in the Row 2, Column 1, of Figure B1. As can be seen, Equation (10) overestimates the actual innovation gains by 10%, the size of the wage premium. Hence, any premium paid to factors over their opportunity costs will directly translate to an overestimation of innovation gain by the measurement framework, to the extent that the use of that factor is reduced as a result of the innovation. The underlying intuition is that the model estimates labor cost savings using wages as a proxy for labor's opportunity costs. Hence, if the wages do not reflect opportunity costs, the measured economic gain will be inaccurate.

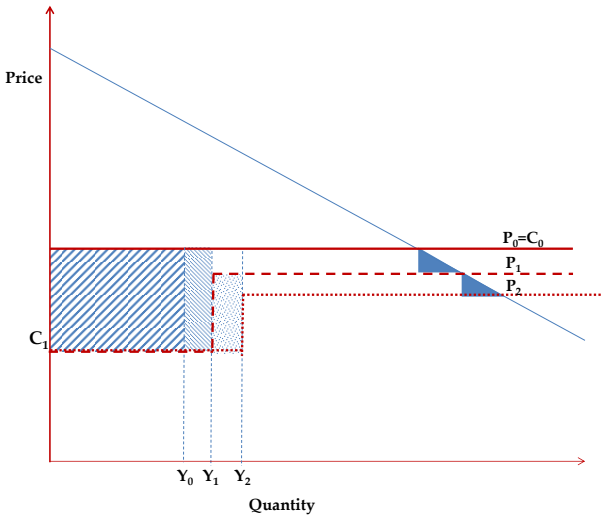
Scenario 3: Quality adjustment error in measuring a WTP increasing innovation

This scenario was used to study the impact of incorrectly measuring the quality increase in a WTP-increasing innovation. In the absence of quantity and price data, the VCA model assumes that the constant-quality price index appropriately adjusts for firm-specific changes in quality. However, it is possible that the price index does not entirely reflect the underlying quality differences. For instance, a firm with a WTP-increasing innovation may choose to grow by passing some or all of the WTP increase to its customers by not increasing the price to match the increase in WTP. On the other hand, the price index may reflect the broader industry behavior which may not be the same as the firm's. To examine this, we considered a scenario where the firm innovates and increases its WTP randomly between 0 and 50% of the first period WTP. We then set a price that was 10% lower than the new WTP. Thus, the price differences underestimate the quality differences by 10%. In line with the Baseline scenario, we assumed that factors are paid their opportunity costs in the first period.

The results are presented in the Row 2, Column 2 of Figure B1. As can be seen, Equation (6) underestimates the actual innovation gains by 10%. The extent of underestimation is largely constant in the size of the innovation. The intuition underlying the underestimation is simple. Because quality changes are measured by changes in price, a lower price through implies a lower measured quality (and hence, WTP) change than in reality. In the extreme, if the firm chooses to keep price constant, no WTP increase (and hence, no economic gain) will be measured.

Scenarios 4-6: Impact of adding extra-marginal (new-to-industry) customers

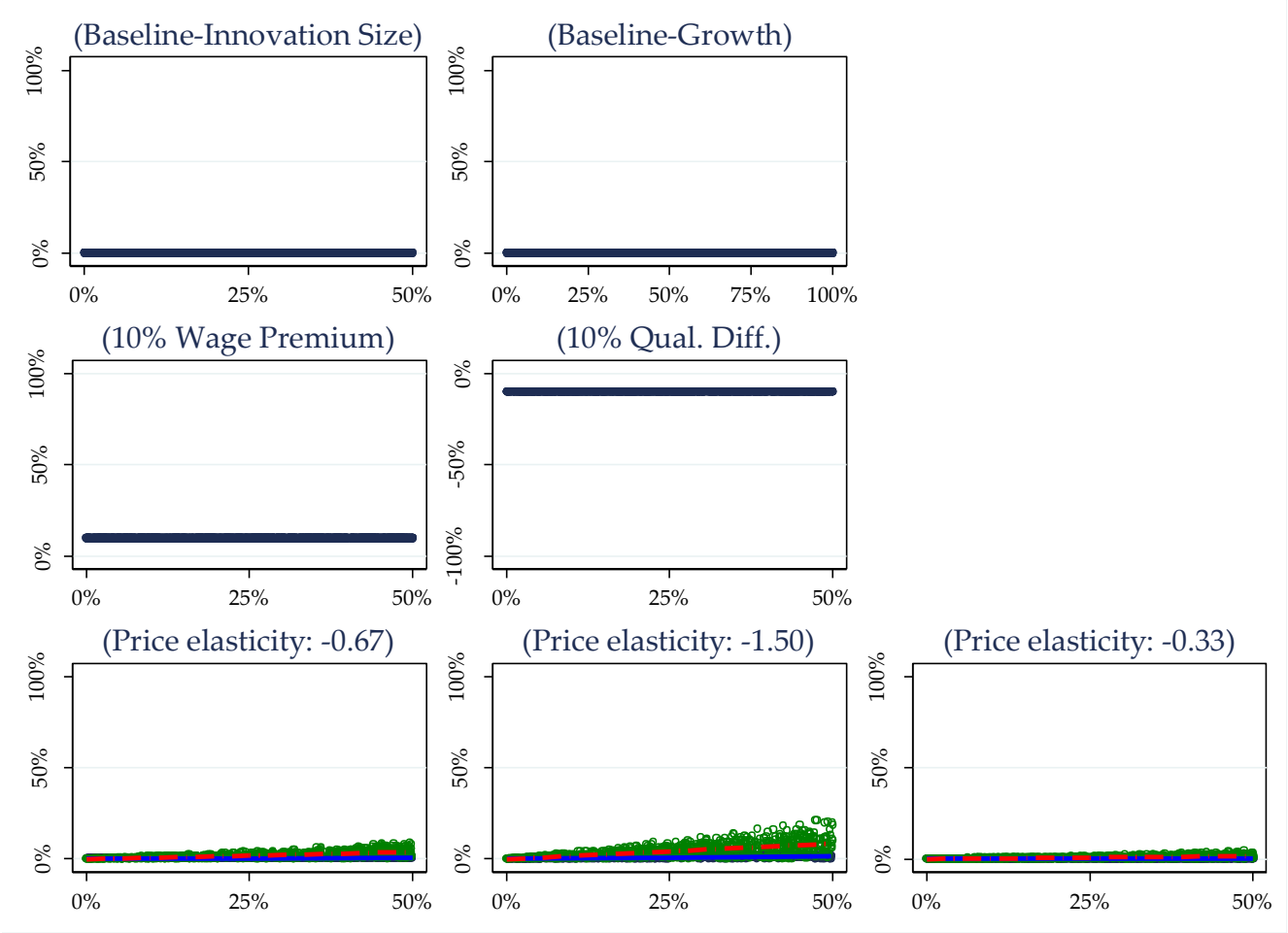
These scenarios relax the assumption that the firm does not add any extra-marginal or new-to-industry customers in the second period. Note that extra-marginal customers come in to the industry only if the industry price falls. Industry price may fall because other competitors innovate or benefit from the focal firm's innovations through spillovers. In either case, the greater the extent of industry price reduction, the greater the number of such new customers in the second period. (See figure aside for a graphical illustration). We allowed two levels of competitor innovation or spillovers. The lower level was set at 10% of the focal firm's innovation size. That is,



if the focal firm was able to reduce unit cost by $1, then the industry competitors decreased their cost (and hence, industry price) by $0.10. The second level was set at 100%. The latter scenario represents extreme spillovers where the firm and is unlikely in reality, especially when examining short time-frames. Of these customers new to the industry, the firm may capture none, some or all of them. The output from new-to-industry customers captured by the firm was randomly varied between 0% and 100% of initial firm output. Note that this mode of growth adds output beyond that from capturing competitors' customers (discussed in the Baseline scenario). As before, we assumed that factors are paid their opportunity costs in the first period.

The results are presented in Row 2 of Figure B1. As can be seen, allowing for extra-marginal growth implies that Equation (10) overestimates the actual innovation gains. The extent of overestimation is increasing in the size of the innovation in all cases. The underlying intuition is that extra-marginal customers in the first period who become customers in the second period have a lower average WTP than the first period customers. Hence, the per-unit economic value created on these growth units is lower than the cost savings per unit. However, the VCA model applies the entire per unit cost savings to all units including to the additional units, thus overestimating the gain. The error is also contingent on the elasticity of demand. In particular, the error is smaller when demand is less elastic and higher when demand is highly elastic. This is consistent with demand increasing more in highly elastic industries than in less elastic industries, in response to a given price change. In line with our intuition, the overestimation is small when the extent of industry growth due to competitor innovations or spillovers is low (the blue line depicts the case where industry innovation is 10% of the focal firm's innovation size). The error is fairly small, less than 3%, even in the most elastic case, and less than 0.75% in the least elastic context. When the extent of industry innovation matches the firm innovation (the industry innovation is 100% of the focal firm's innovation size), the error is larger though it is less than 10% in the low and medium elasticity scenarios. In the high elasticity scenario, the maximum error is a little over 21% but less than 8% of the cases in that scenario have an error over 10%. In particular, only those firms with very large innovation sizes (mean size of 42.6% for these large error cases compare to 23.2% for cases with errors less than 10%) or very high growth from new-to-industry customers have these larger errors (mean output increase from these customers was about 80% of initial output for the large error cases compared to 46% for those with errors less than 10%).

Figure B1: Results of Simulation Analyses



*Note: The vertical axis in these graphs is **model measurement error**. The horizontal axis in all graphs except the "Baseline–Growth" is **innovation size**. The horizontal axis in the "Baseline–Growth" is **firm growth from current industry customers**. Two different levels of industry value creation (or spillovers) are presented. The solid dark navy circles and the solid blue line refer to industry value creation (or spillovers) set at 10% of firm innovation. The hollow green circles and the dashed red line refer to industry value creation (or spillovers) set at 100% of firm innovation. The lines are best fit linear plots of the corresponding scatter plots. The output from new-to-industry customers captured by the firm varies randomly from 0 to 100% of the initial firm output. s*

ONLINE APPENDIX C

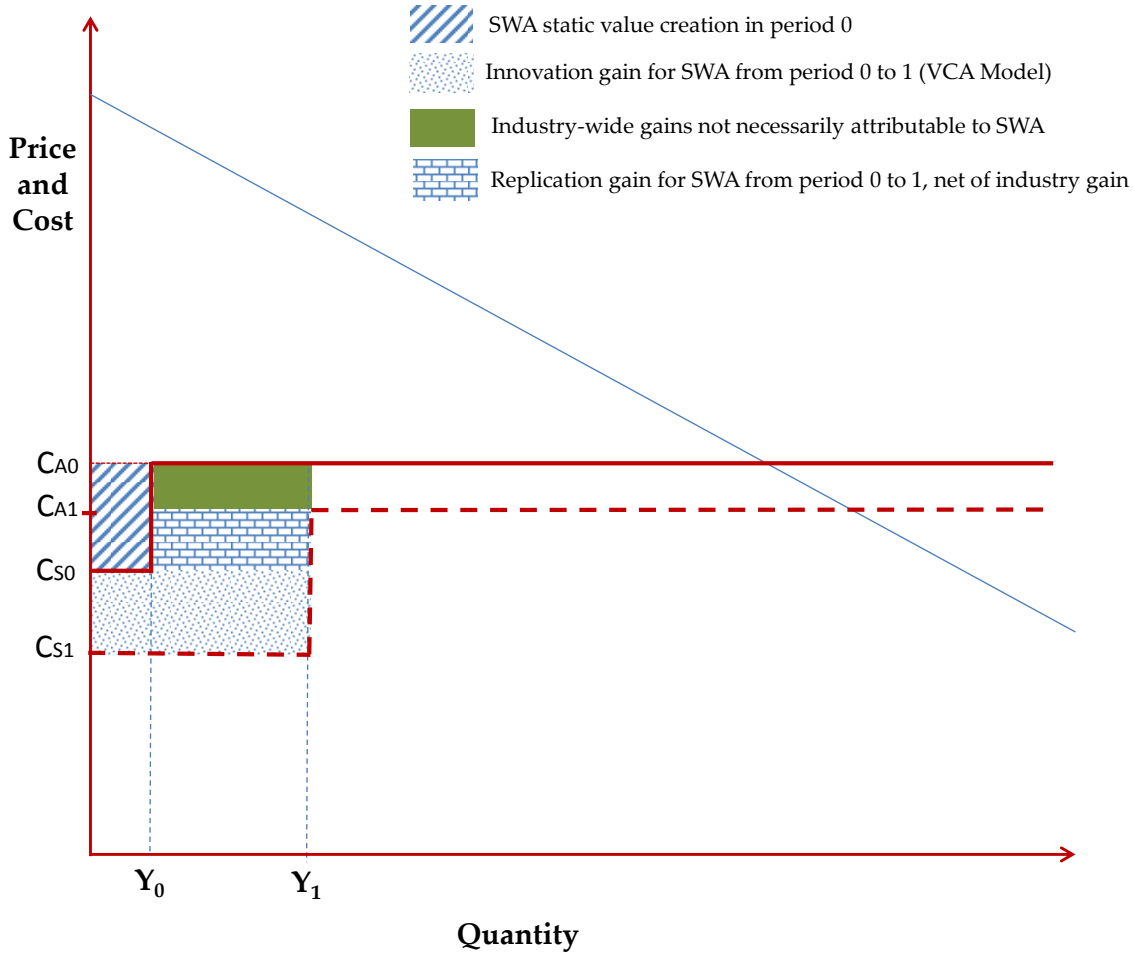
This appendix discusses the issue of competitors innovating simultaneously as the focal firm. When both firms are innovating, then one firm's replication gain may subsume part of another firm's innovation gain. To be more precise, consider Figure C1 which interprets innovation and replication gain in the situation where firms are simultaneously innovating. Between period 0 and period 1, the more efficient firm (Firm 1 or SWA), reduces its unit cost from C_{S0} to C_{S1}, while increasing output from Y_0 to Y_1. Firm 2 (or AA), which we assume is representative of all other firms in the industry, reduces unit cost from C_{A0} to C_{A1}.

Firm 1's innovation gain can be shown as an area on the graph. Specifically, it is the dotted rectangle defined by the resource savings (C_{S0} minus C_{S1}) and the new output (Y_1). This area is equal to the innovation gain as defined in Equation (2), where the resource savings can be measured by Equation (10) as a percentage of prior period real output.[11]

Firm 1's replication gain can be interpreted in a similar manner. In the case where Firm 2 achieves no innovation gain (i.e., $C_{A0} = C_{A1}$), Firm 1's replication gain is the rectangle defined by the difference in the two firms' costs in the initial period (C_{A0} minus C_{S0}), multiplied by the expansion in Firm 1's output (Y_1 minus Y_0). However, if Firm 2 is also improving over time, a conservative estimate of Firm 1's replication gain would net out the gains made by Firm 2 (the solid green rectangle), as shown in the figure. (This corresponds to the choice of whether to apply Equation (13) in the initial year, or the ending year, to compute the differential between the two firms.) If part of Firm 2's gains came through spillovers of Firm 1's efforts, then some part of the solid green rectangle can be attributed to Firm 1.

[11] More specifically, the area of the rectangle defined by the resource savings (CS_0 minus CS_1) and the initial Y_0 is the first term in Equation (2), and the area of the rectangle defined by the resource savings (CS_0 minus CS_1) and output expansion (Y_1 minus Y_0) is equal to the second term in Equation (2). An alternative way to define innovation gain would have been as the first term in Equation (2), that is, the area of the rectangle defined by the resource savings and the initial Y_0. However, we prefer our definition given its consistency with the measurement framework.

Figure C1. Categorization of Gains when Both Firms are Innovating



ONLINE APPENDIX D: DATA AVAILABILITY AND THE VCA MODEL

At a basic level, using the minimal setup of the VCA model—using *value added* rather than output—, one needs the following data to estimate value creation and capture for three stakeholder groups (employees, customers and shareholders):

- GDP deflator (GDP)
- Producer Price Index (PPI)
- Revenues (REV)
- Cost of goods sold (COGS)
- SG&A expenses (XSGA)
- Employment (EMP)
- Wages & Salaries (XLR)
- Capital (PPENT)

These data can be obtained from several sources. First, we focus on available accounting data and then on price indexes–GDP deflator statistics by country can be easily obtained from public sources.

A exploratory survey in *Compustat (Global)* of 405,424 firm-year observations in 115 countries from 1996-2010 shows the following:

Variable	**Firm-year obs.**	**% availability**
revt	384,192	94.8%
cogs	372,182	91.8%
xsga	344,410	85.0%
emp	228,998	56.5%
xlr	141,856	35.0%
ppent	381,369	94.1%

As expected, wages and salaries is clearly the limiting variable. Still, this item is available for 35% of the observations (141,856 firm-years), a respectable number which allows to apply the VCA model (using value added) in a large number of industries. In total, we find that there is a wealth of 87,000 firm-year observations with fully available data on all required items (21% of the sample). Moreover, the population of 405,424 firm-years covers 115 different countries (e.g., 124,785 obs. in USA, 41,822 in Japan, 9,288 in Germany) which allows for rich cross-national comparisons in value production and capture.

Considering that XLR is clearly the limiting variable, we show next the number of firm-year observations with available XLR data (1996–2010) for the top 30 countries in number of observations:

Country	Firm-year observations
USA	19,240
GBR	16,439
IND	13,404
AUS	9,204
FRA	8,096
DEU	7,876
HKG	7,466
MYS	7,039
SGP	4,448
SWE	3,880
ITA	2,871
CHE	2,580
THA	2,574
CAN	2,527
NOR	2,151
NLD	2,098
IDN	1,918
POL	1,763
BRA	1,752
CHN	1,684
ESP	1,655
FIN	1,599
ZAF	1,565
DNK	1,523
BEL	1,246
PAK	1,146
ISR	1,143

Next, we show a breakout of 2-SIC industries (worldwide) and the number of firm-year observations with available data on XLR:

Industry (2-digit SIC)	Firm-year
01 Agricultural Production - Crops	657
02 Agricultural Production - Livestock	224
07 Agricultural Services	92
08 Forestry	141
09 Fishing, Hunting, & Trapping	54
10 Metal, Mining	5,758
12 Coal Mining	478
13 Oil and Gas Extraction	2,952
14 Nonmetallic Minerals, except Fuels	603
15 General Building Contractors	1,842
16 Heavy Construction, Except Building	1,760
17 Special Trade Contractors	532
20 Food & Kindred Products	7,096
21 Tobacco Products	258
22 Textile Mill Products	2,268
23 Apparel & Other Textile Products	1,874
24 Lumber & Wood Products	1,127
25 Furniture & Fixtures	641
26 Paper & Allied Products	2,082
27 Printing & Publishing	2,186
28 Chemical & Allied Products	9,651
29 Petroleum & Coal Products	1,243
30 Rubber & Miscellan. Plastics Products	2,259
31 Leather & Leather Products	495
32 Stone, Clay, & Glass Products	3,234
33 Primary Metal Industries	3,771
34 Fabricated Metal Products	2,216
35 Industrial Machinery & Equipment	5,981
36 Electronic & Other Electric Equipment	6,999
37 Transportation Equipment	3,327
38 Instruments & Related Products	3,046

39 Misc. Manuf. Industries	1,206
40 Railroad Transportation	298
41 Local & Interurban Passenger Transit	333
42 Trucking & Warehousing	840
44 Water Transportation	1,716
45 Transportation by Air	1,329
46 Pipelines except gas	23
47 Transportation Services	1,473
48 Communications	4,274
49 Electric, Gas, & Sanitary Services	4,569
50 Wholesale Trade- Durable Goods	3,641
51 Wholesale Trade- Nondurable Goods	2,003
52 Building Materials, Gardening Supplies	261
53 General Merchandise Stores	857
54 Food Stores	738
55 Automotive Dealers & Service Stations	501
56 Apparel & Accessory Stores	684
57 Furniture & Homefurnishings Stores	502
58 Eating & Drinking Places	1,543
59 Miscellaneous Retail	1,258
60 Depository Institutions	11,229
61 Nondepository Institutions	855
62 Security & Commodity Brokers	1,132
63 Insurance Carriers	349
64 Insurance Agents, Brokers, & Service	331
65 Real Estate	432
67 Holding & Other Investment Offices	1,032
70 Hotels & Other Lodging Places	1,520
72 Personal Services	178
73 Business Services	13,031
75 Auto Repair, Services, & Parking	210
76 Miscellaneous Repair Services	24
78 Motion Pictures	1,028

79 Amusement & Recreation Services	1,522
80 Health Services	1,330
81 Legal Services	24
82 Educational Services	326
83 Social Services	65
84 Museums, Gardens	49
87 Engineering & Management Services	2,466
89 Miscelaneous	93
99 Non classifiable	1,530

Turning to price indexes, Producer Price Index (PPI) data can be obtained from several sources. A PPI for an industry is a measure of changes in prices received for the industry's output sold outside the industry (that is, its net output).

The Bureau of Labor Statistics (BLS) in USA (www.bls.gov/ppi) publishes approximately 535 industry price indexes in combination with over 4,000 specific product line and product category sub-indexes, as well as, roughly 500 indexes for groupings of industries.

We show below some of the aggregated sectors for which PPI indexes are regularly reported by the BLS:

Producer Price Index (PPI). Industry Classification

SERIES ID

pcu111 Crop Production
pcu112 Animal production
pcu113 Forestry and Logging
pcu114 Fishing, Hunting and Trapping
pcu115 Support Activities for Agriculture and Forestry
pcu211---211--- Oil and gas extraction
pcu212---212--- Mining (except oil & gas)
pcu213---213--- Mining support activities
pcu221---221--- Utilities
pcu236211236211 New industrial building construction
pcu311---311--- Food mfg
pcu312---312--- Beverage & tobacco mfg
pcu313---313--- Textile mills
pcu314---314--- Textile product mills
pcu315---315--- Apparel manufacturing
pcu3151--3151-- Apparel knitting mills
pcu316---316--- Leather and allied product manufacturing
pcu321---321--- Wood product manufacturing

pcu322---322---	Paper manufacturing
pcu323---323---	Printing and related support activities
pcu324---324---	Petroleum and coal products manufacturing
pcu325---325---	Chemical mfg
pcu326---326---	Plastics and rubber products mfg
pcu327---327---	Nonmetallic mineral product manufacturing
pcu331---331---	Primary metal mfg
pcu332---332---	Fabricated metal product mfg
pcu333---333---	Machinery manufacturing
pcu334---334---	Computer & electronic product mfg
pcu335---335---	Electrical equipment and appliance mfg
pcu336---336---	Transportation equipment manufacturing
pcu337---337---	Furniture & related product mfg
pcu339---339---	Miscellaneous mfg
pcu423---423---	Merchant wholesalers, durable goods
pcu424---424---	Merchant wholesalers, nondurable goods
pcu425---425---	Wholesale trade agents and brokers
pcu429930429930	Material recyclers
pcu441---441---	Motor vehicle and parts dealers
pcu442---442---	Furniture and home furnishings stores
pcu443---443---	Electronics and appliance stores
pcu444---444---	Building material and garden equipment and supply dealers
pcu445---445---	Food and beverage stores
pcu446---446---	Health and personal care stores
pcu447---447---	Gasoline stations
pcu448---448---	Clothing and clothing accessories stores
pcu451---451---	Sporting goods, hobby, and book stores
pcu452---452---	General merchandise stores
pcu4531--4531--	Florists
pcu454---454---	Nonstore retailers
pcu481---481---	Air transportation
pcu482---482---	Rail transportation
pcu483---483---	Water transportation
pcu484---484---	Truck transportation
pcu4861--4861--	Pipeline transportation of crude oil
pcu488---488---	Transportation support activities
pcu491---491---	U.S. Postal Service
pcu492---492---	Couriers and messengers
pcu493---493---	Warehousing and storage
pcu511---511---	Publishing industries, except Internet

pcu515---515---	Broadcasting, except Internet
pcu517---517---	Telecommunications
pcu5182--5182--	Data processing and related services
pcu519130519130	Internet publishing and web search portals
pcu5221--5221--	Depository credit intermediation
pcu523---523---	Security, commodity contracts and like activity
pcu524---524---	Insurance carriers and related activities
pcu53112-53112-	Lessors of nonresidential buildings (except miniwarehouses)
pcu5321--5321--	Automotive equipment rental and leasing
pcu5411--5411--	Legal services
pcu5613--5613--	Employment services
pcu5621--5621--	Waste collection
pcu61142-61142-	Computer training
pcu6211--6211--	Offices of physicians
pcu622---622---	Hospitals
pcu6231--6231--	Nursing care facilities
pcu7131--7131--	Amusement and theme parks
pcu721---721---	Accommodation
pcu811	Repair and Maintenance
pcu812	Personal and Laundry Services
pcu813	Religious, Grantmaking, Civic, Professional, and Similar Organizations
pcu814	Private Households
pcu999	Federal, State and Local Goverment
pcu924126924126	Premiums for property and casualty insurance

In addition, the BLS provides specific PPI for more disaggregated industries and market segments. For instance, the following PPI indexes and sub–indexes are available for air transportation:

481---	Air transportation
4811--	Scheduled air transportation
48111-	Scheduled air transportation
481111	Scheduled passenger air transportation
	-Domestic
	-First Class
	-Coach
	-International
	-Primary services
	-Other receipts
481112	Scheduled freight air transportation

-Freight

-Mail

-Primary services

-Other receipts

4812-- Nonscheduled air transportation

48121- Nonscheduled air transportation

481211 Nonscheduled air passenger chartering

481212 Nonscheduled air freight chartering

Crucially, the PPI high level of detail potentially allows researchers using the VCA method to incorporate *quality changes* for several inputs and outputs in their analyses.

Another comprehensive source for price indexes is the World KLEMS initiative (www.worldklems.net) that provides detailed price data for a large number of industries in many different countries, including most European states, USA and large economies such as Canada, Japan, Korea, Australia, China, Russia, Argentina or Mexico.

APPENDIX E: FLOW CHART FOR APPLYING THE VCA MODEL