Appendix A Additional charts for calibrated examples

This appendix shows a number of charts describing profit, autarky threats, compatibility regimes and auction results that supplement the examples in the paper for a range of network strength and technological improvements.

Incumbent monopoly

Profits under compatibility

The figures below show the profit function under compatibility for positive output by firms for an entrant's innovation up to twice the incumbent quality level: (1) for the incumbents and the entrant; and (2) for incumbent if the it acquires the innovation.

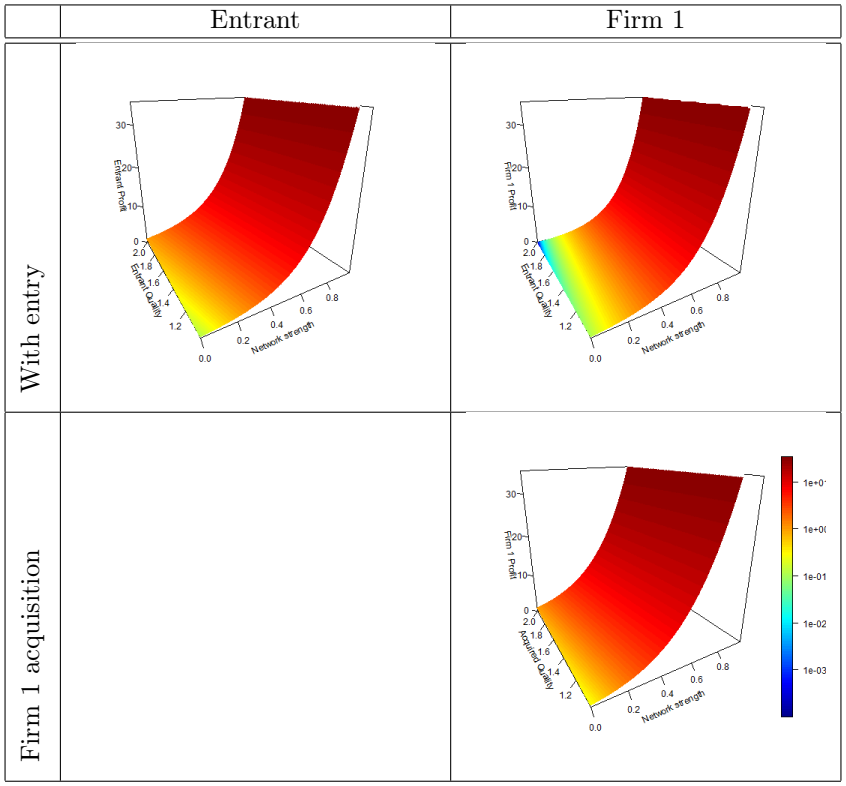

Figure 1: Profits under compatibility: with entry; and with acquisition by the incumbent

Note: Colours are all shown on the same log scale between zero and 35 to show relative changes.

If entry occurs and compatibility is agreed, the incumbent and entrant have the profit function:

$$\pi_i = \left(A_i + (\alpha - 1)\left(q_i + q_j\right) + \alpha\left(b_i + b_j\right) - c\right)^2. \tag{1}$$

where j indicates the output and installed base of the firm's rival. If the innovation is acquired by the incumbent, its profit is

$$\pi_1 = \left(A_e + (\alpha - 1)\, q_1 + \alpha\left(b_1 + b_e\right) - c\right)^2. \tag{2}$$

where e indicates the properties of the entrepreneur's innovation that the incumbent has acquired and q_1 is determined on the basis of the incumbent's acquired quality improvement.

Profits under autarky

The figures below show the profit function under autarky for positive output by firms for an entrant's innovation up to twice the incumbent quality level: (1) for the incumbents and the entrant; and (2) for incumbent if the it acquires the innovation.

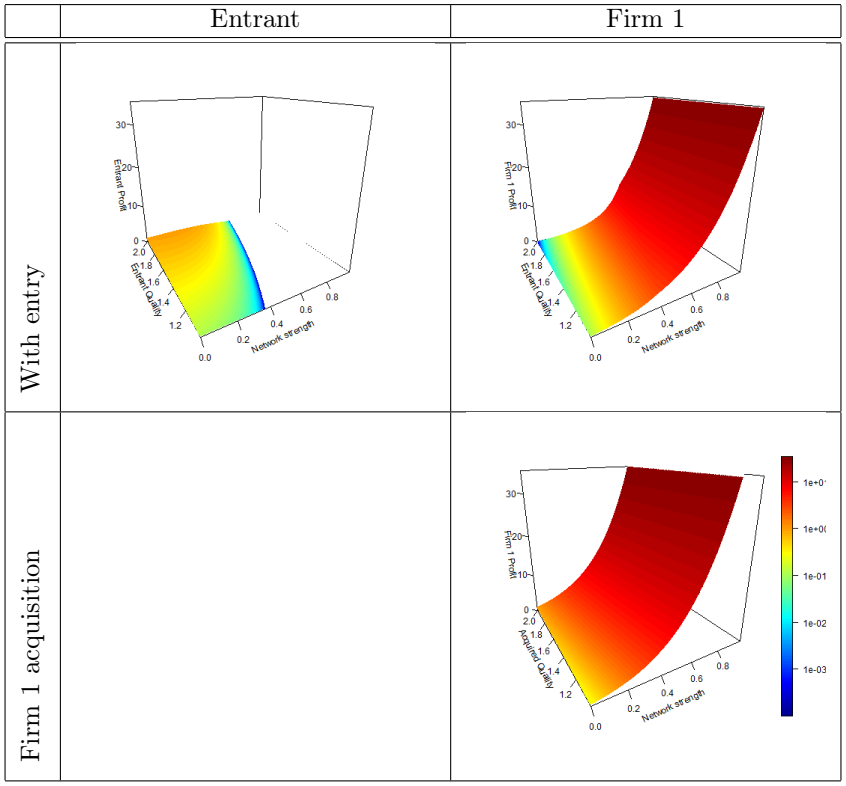

Figure 2: Profits under autarky: with entry; and with acquisition by the incumbent

Note: Colours are all shown on the same log scale between zero and 35 to show relative changes.

If entry occurs and compatibility is not agreed, the incumbent's profit function is given by

$$\pi_1 = (A_1 + (\alpha - 1)\, q_1 + \alpha b_1 - q_e - c)^2 \,. \tag{3}$$

and the entrant's profit function is

$$\pi_e = (A_e + (\alpha - 1)\, q_e + \alpha b_e - q_1 - c)^2 \,. \tag{4}$$

If the innovation is acquired by the incumbent its profits is as above in Equation 2. The figures show the profit function under compability for positive output by firms for an entrant's innovation up to twice the incumbent quality level: (1) for the incumbent and the entrant; and (2) for the incumbent if if acquires the innovation.

The relationship between profits, compatibility and innovation incentives

The incumbent's payoff can be enhanced by threatening to impose autarky on the entrant, thereby lowering the entrepreneur's reserve. The red shading in Figure 3 shows the combination of network strength and quality improvement where the incumbent will threaten autarky. As a result, the entrepreneurs reserve and their payoff for innovation is less in this autarky region. In response, for sufficiently weak network effects, entrepreneurs face a trade off between targeting incremental innovations, with a high likelihood of success and losing compatibility, or targeting more substantial innovations with a lower probability of success that

maintain compatibility. However, for a small range of sufficiently strong network effects, entrepreneurs face a trade off between targeting more substantial innovations and losing compatibility.

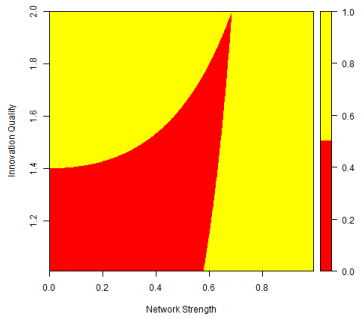

Figure 3: Credible threats of autarky

The auction determines ownership of the innovation and the compatibility regime of subsequent competition. The compatibility regime of subsequent competition is shown in Figure 4 with red shading for autarky and yellow for compatibility. For very drastic innovations, where autarky is not a credible threat, the innovation is acquired and the monopoly network is effectively autarkic.

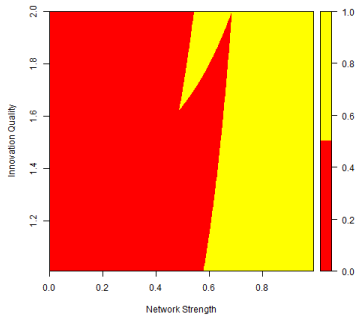

Figure 4: Compatibility regime

The green shading in Figure 5 shows the combination of network strength and quality improvement where the entrepreneur would enter as a result of the auction and the grey region describes where the innovation is acquired by the incumbent. If the incumbent credibly threatening autarky, it is able to acquire the innovation. For weak to moderate network effects the entrepreneur will sell the innovation to the incumbent, as the incumbent maintains its highest profit by sustaining its monopoly and paying at least the entrepreneur's reserve, even if autarky cannot be credibly threatened. For strong network effects, the incumbent cannot credibly threaten autaky because it would benefit from it's own network accessing the network of a high quality entrant and the entrant's best response is to enter with a new firm.

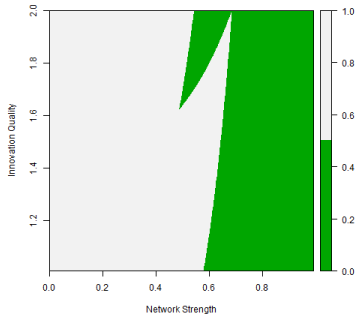

Figure 5: Ownership

Multiple incumbent firms

Profits under compatibility

Each participant has the profit function:

$$\pi_i = \left(A_i + (\alpha - 1) \sum_{j=1}^{n} q_j + \alpha \sum_{j=1}^{n} b_j - c \right)^2 \tag{5}$$

where $\sum_{j=1}^{n} q_j$ is defined in the article. The charts in Figure 6 show the profit function under compability for positive output by firms for an entrant's innovation up to twice the incumbent quality level: (1) for the two incumbents and the entrant; (2) for the two incumbents if the smaller incumbent acquires the innovation; and (3) for the two incumbents if the larger incumbent acquires the innovation. As in typical models with network effects, profit is increasing with network strength for all firms. The entrepreneur's profit is increasing in the quality of its innovation. Incumbents' profits decline in the quality of an entrant's innovation, but the rate of decline reduces to zero as network externalities tend towards the theoretical maximum of one. Alternatively, if acquired by an incumbent the acquiring firm's profit is increasing in the quality of its acquired innovation whereas the other incumbent's profit is decreasing in the quality of its competitor's acquired innovation. Nonetheless, the non acquiring incumbent's profit is still higher when it only has one rival than when an entrepreneur chooses to enter, but the extent of this additional benefit diminishes with network strength.

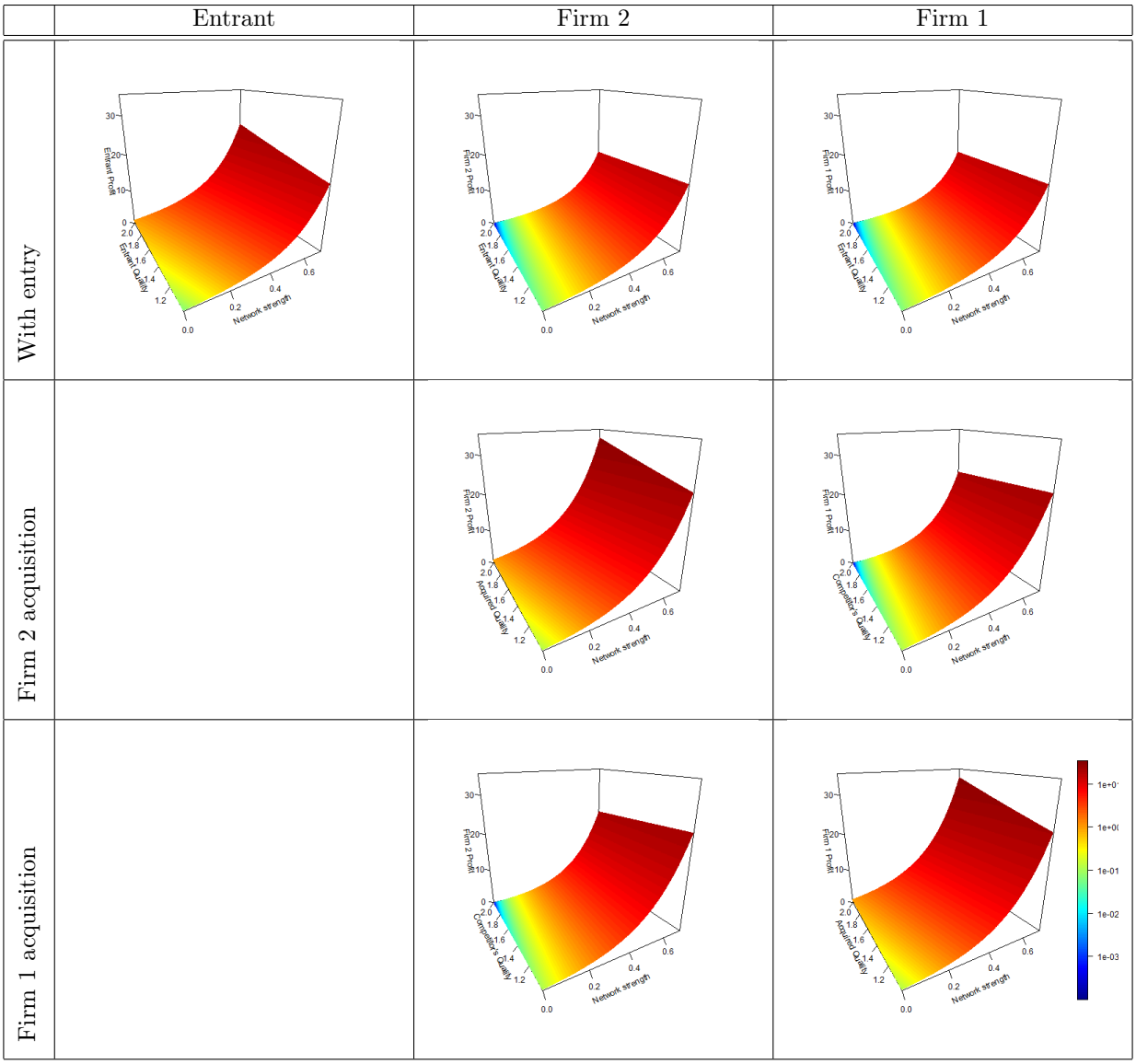

Figure 6: Profits under compatibility: with entry; with acquisition by small incumbent (Firm 2); and with acquisition by large incumbent (Firm 1)

Note: Colours are all shown on the same log scale between zero and 35 to show relative changes.

Profits under autarky

Firm 1 has the profit function

$$\pi_1 = \left(\alpha q_1 + A_1 + \alpha b_1 - \sum_{i=1}^{n} q_i - c \right)^2 . \tag{6}$$

Competitors to Firm 1 have the profit function

$$\pi_i = \left(A_i + (\alpha - 1) \sum_{j=1}^{n} q_j - \alpha q_1 + \alpha \sum_{j=2}^{n} b_j - c \right)^2 . \tag{7}$$

The charts in Figure 7 show the profit function under autarky for positive output by firms for an entrant's innovation up to twice the incumbent quality level: (1) for the two incumbents and the entrant; (2) for

the two incumbents if the smaller incumbent acquires the innovation; and (3) for the two incumbents if the larger incumbent acquires the innovation.

As is typical in models with network effects, the profit of firms with the largest installed base increases with network strength. However, for smaller firms, profits initially increase with network strength but diminish at higher levels as network size becomes a more important factor for consumers than quality when network effects are strong. This is particularly apparent when the second largest incumbent acquires the innovation such that profit initially increases with network strength and later diminishes even when quality is substantially higher than the quality of the rival variety. The entrant's profit is increasing in the quality of its innovation. Incumbents' profits decline in the quality of an entrant's innovation, but the rate of decline diminishes as network effects increase. Alternatively, the acquiring firm's profit is increasing in the quality of its acquired innovation whereas the other incumbent's profit is decreasing in the quality of its competitor's acquired innovation. The dominant incumbent's profit diminishes only slightly if the other incumbent acquires the innovation, but is still higher than if it faces competition from an entrant.

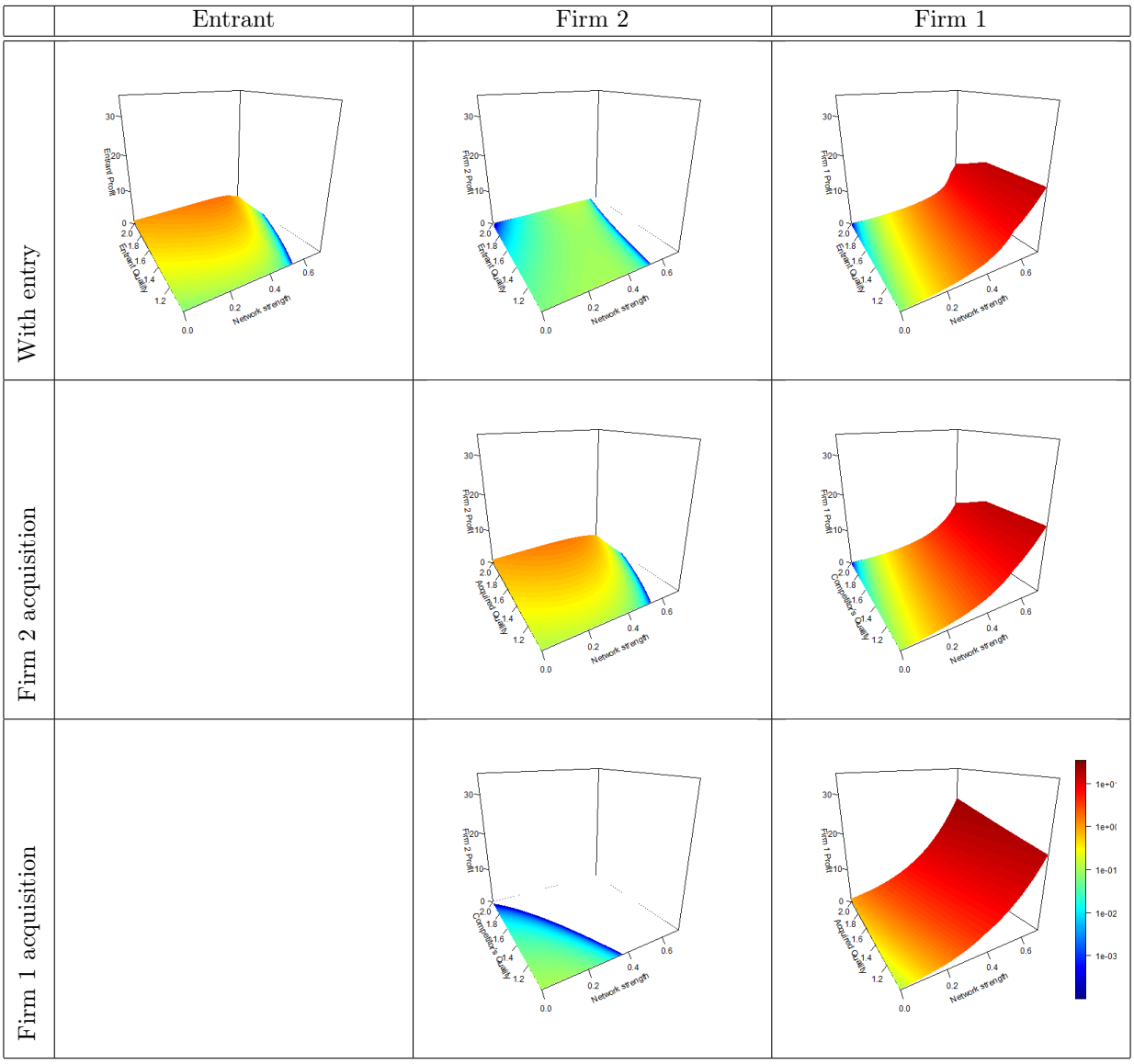

Figure 7: Profits under autarky: with entry; with acquisition by small incumbent (Firm 2); and with acquisition by large incumbent (Firm 1)

Note: Colours are all shown on the same log scale between zero and 35 to show relative changes.

The red shading in the charts in Figure 8 show the combination of network strength and quality improvement where the incumbent will threaten autarky if following the auction entry were to occur or the innovation were acquired by Firm 2 or Firm 1 respectively. The incumbent's payoff can be enhanced by threatening to impose autarky on the entrant, thereby lowering the entrepreneur's reserve. Similarly, the subtle threat that autarky would be imposed if Firm 1 acquired the innovation incentivises Firm 2 to acquire the innovation and enhances Firm 1's payoff because it can still access the larger installed bases of both firms. As a result, the entrepreneurs reserve and their payoff for innovation is less in this autarky region.

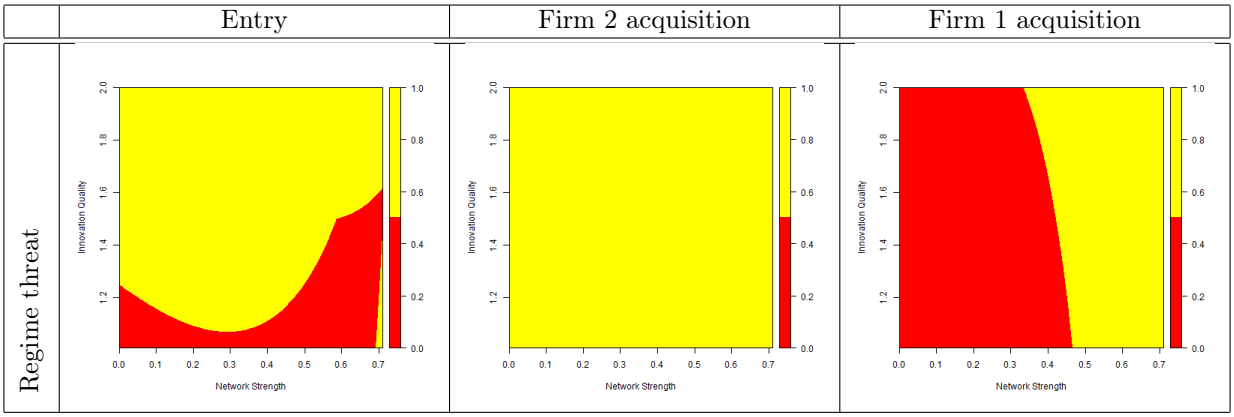

Figure 8: Credible threats of autarky if acquired by each firm

The dark green shading in Figure 9 shows the combination of network strength and quality improvement where the entrepreneur would enter as a result of the auction, the grey region describes where the innovation is acquired by the largest incumbent, the light green region describes where Firm 2 acquires the innovation by bidding higher than either the reserve or Firm 1's bid and the brown region represents a tied auction between Firm 1 and Firm 2 where each is indifferent between acquiring the innovation or allowing its rival incumbent to acquire the innovation.

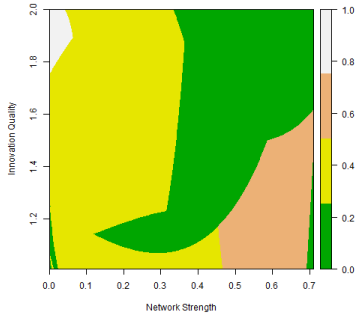

Figure 9: Ownership

For weak to moderate network effects the entrepreneur will sell the innovation to an incumbent, as both incumbents maintains their highest profit by sustaining its monopoly and paying at least the entrepreneur's reserve, even if autarky cannot be credibly threatened. For strong network effects, the incumbent cannot credibly threaten autaky because it would benefit from it's own network accessing the network of a high quality entrant and the entrant's best response is to enter with a new firm.

The shaded areas in Figure 10 describes which firm offered the 2nd highest bid. The dark green region represents the entrepreneur, such that only one bidder was willing to exceed the entrepreneur's reserve. As a result the winning bid only needs to bid the entrepreneur's reserve in order to win the auction. In this example, Firm 2 out bid the reserve, but Firm 1's bid was below the entrepreneur's reserve. In this area, the

returns to the entrepreneur are equal to their reserve. The light green region represents Firm 2. Comparing with Figure 9, the region in the top left describes a bidding rivalry between Firm 1 and Firm 2 such that the acquisition price of the innovation exceeded the entrepreneur's reserve. In the other light green region, Firm 2 acquires the innovation for a price equal to the entpreneur's reserve and Firm 1's bid was below the reserve. The grey region represents Firm 1.

In this example, bidding rivalry between Firm 1 and Firm 2 increased the price of the innovation above the entrepreneur's reserve, with Firm 2 winning the auction. Furthermore, Firm 2 is bidding strategically to avoid Firm 1 imposing an autarky regime were Firm 1 to win the auction. The brown region represents a tie between Firm 1 and Firm 2. Examining Figure 9, the brown region in that figure represents where the winning bid is a tie between Firm 1 and Firm 2, above the entrepreneur's reserve because of the threat of autarky that would be imposed were the entrepreneur to enter the market. The remainder of the brown region in Figure 10 represents where Firm 1 and Firm 2 had tied bids, but the entrepreneur has a higher reserve because there is no credible threat of autarky.

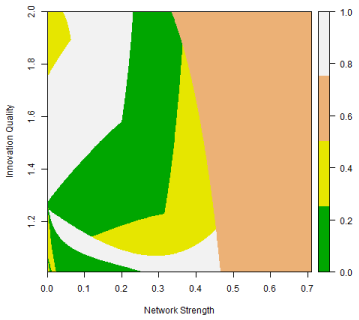

Figure 10: Losing bidder

The auction determines ownership of the innovation and the compatibility regime of subsequent competition. The compatibility regime of subsequent competition is shown in Figure 11 with red shading for autarky and yellow for compatibility. For very drastic innovations, where autarky is not a credible threat, the innovation is acquired and the monopoly network is effectively autarkic.

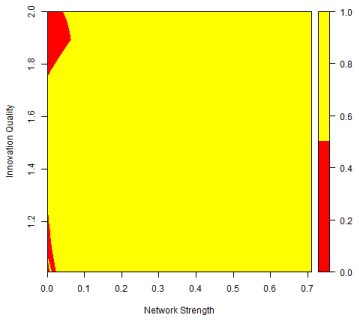

Figure 11: Compatibility regime