RAND Journal of Economics
Vol. 33, No. 4, Winter 2002
pp. 630–649

Too cool for school? Signalling and countersignalling

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In signalling environments ranging from consumption to education, high-quality senders often shun the standard signals that should separate them from lower-quality senders. We find that allowing for additional, noisy information on sender quality permits equilibria where medium types signal to separate themselves from low types, but high types then choose to not signal, or countersignal. *High types not only save costs by relying on the additional information to stochastically separate them from low types, but countersignalling itself is a signal of confidence that separates high types from medium types. Experimental results confirm that subjects can learn to countersignal.*

For Nash to deviate from convention is not as shocking as you might think. They were all prima donnas. If a mathematician was mediocre he had to toe the line and be conventional. If he was good, anything went.

Z. Levinson, from *A Beautiful Mind*
(Nasar, 1998, p. 144)

1. Introduction

■ Following in the tradition of Veblen's (1899) analysis of conspicuous consumption and Akerlof's (1970) model of adverse selection, Spence's (1973a, 1974) signalling model of overeducation showed how seemingly wasteful actions can be valued as evidence of unobservable quality. Signalling models have since been applied to economic phenomena from advertising (Nelson, 1974) to financial structure (Ross, 1977), social phenomena from courtship (Spence, 1973b) to gift exchange (Camerer, 1988), and biological phenomena from a peacock's plumage

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We thank Chris Avery, Bruno Broseta, William Hamilton, Robin Hanson, John Hardman-Moore, John Kagel, Barry Nalebuff, Al Roth, Karl Schlag, seminar participants at various conferences and departments, two anonymous referees, and the Editor Lars Stole. All remaining errors are a signal of our quality. Harbaugh thanks the Yale School of Management for postdoctoral support.

(Zahavi, 1975) to a tree's autumn foliage (Brown and Hamilton, 1996). These models conclude that in a separating equilibrium, "high" types (high in productivity, wealth, fecundity, or some other valued attribute) send a costly signal to differentiate themselves from lower types.

Contrary to this standard implication, high types sometimes avoid the signals that should separate them from lower types, while intermediate types often appear the most anxious to send the "right" signals. The nouveau riche flaunt their wealth, but the old rich scorn such gauche displays. Minor officials prove their status with petty displays of authority, while the truly powerful show their strength through gestures of magnanimity. People of average education show off the studied regularity of their script, but the well educated often scribble illegibly. Mediocre students answer a teacher's easy questions, but the best students are embarrassed to prove their knowledge of trivial points. Acquaintances show their good intentions by politely ignoring one's flaws, while close friends show intimacy by teasingly highlighting them. People of moderate ability seek formal credentials to impress employers and society, but the talented often downplay their credentials even if they have bothered to obtain them. A person of average reputation defensively refutes accusations against his character, while a highly respected person finds it demeaning to dignify accusations with a response.

How can high types be so understated in their signals without diminishing their perceived quality? Most signalling models assume that the only information available on types is the signal, implying that high types will be confused with lower types if they do not signal. But in many cases other information is also available. For instance, wealth is inferred not just from conspicuous consumption, but also from information about occupation and family background. This extra information is likely to be noisy in that the sender cannot be sure what the receiver has learned, implying that medium-quality types may still feel compelled to signal to separate themselves from low types. But even noisy information will often be sufficient to adequately separate high types from low types, leaving high types more concerned with separating themselves from medium types. Since medium types are signalling to differentiate themselves from low types, high types may choose to not signal, or "countersignal," to differentiate themselves from medium types.

We investigate such countersignalling behavior formally with a model that incorporates extra, noisy information on type into a signalling game. We find that countersignalling can emerge as part of a standard perfect Bayesian equilibrium in which all players are forming rational beliefs and are acting rationally given these beliefs. Countersignalling is naturally interpreted as a sign of confidence.[1] While signalling proves the sender is not a low type, it can also reveal the sender's insecurity. Since medium types have good reason to fear that the extra information on type will not differentiate them from low types, they must signal to clearly separate themselves. In contrast, high types can demonstrate by countersignalling that they are confident of not being confused with low types. This possibility arises because in a countersignalling equilibrium, the sender's expectation over the receiver's beliefs about her type depends on both the signal and her type, not just on the signal.

The extra information on type in our model can be seen as a second signal following the literature on multidimensional signals (Quinzii and Rochet, 1985; Engers, 1987). This literature is concerned primarily with whether such signals can ensure complete separation when sender type varies in multiple dimensions. We assume that sender type varies in only one dimension and concentrate instead on the opposite problem of how the extra information can encourage partial pooling rather than complete separation.[2] Given the noisy nature of the extra information, it might seem that high types should signal to further emphasize their quality. Instead, we find that the information asymmetry arising from the noisy extra information can give perverse incentives. Pooling with low types can become a signal in itself—a way for high types to show their confidence

[1] This point was made by Confucius (13:26, *The Analects*): "The Superior Man is self-confident without being arrogant. The inferior man is arrogant and lacks self-confidence."

[2] Hertzendorf (1993) also allows for two signals, one of which is noisy, but considers only two types of senders, precluding the possibility of countersignalling.

that the extra information is favorable to them by taking an action that is too risky for medium types.

Because countersignalling serves as a signal of confidence, we show that it is more than just the absence of signalling by types whose high quality is already evident and who wish to save costs. First, when the extra information sufficiently differentiates high types from low types, signalling can actually lower a high sender's estimated type. Countersignalling can therefore arise even when signalling is a desirable activity that high types would pursue in a perfect information environment. Second, countersignalling reduces the efficiency of receiver estimates of sender quality. Since countersignalling depends on the existence of additional information on sender quality, eliminating this information can actually increase estimate efficiency. Third, when there is a range of possible signals, high types not only choose a cheaper signal than medium types, but choose the same cheap signal being sent by low types. Only by pooling with low types can high types successfully discourage medium types from mimicking their behavior. Fourth, low signalling costs can paradoxically reduce signalling by encouraging high types to countersignal. In an educational context, an increase in the difficulty of an assignment can therefore "challenge" high-ability students to stop countersignalling and to send the signal of completing it. Finally, standard refinements do not predict a unique equilibrium but allow for multiple equilibria, including mixed-strategy equilibria in which some high types signal while others countersignal and "counter-countersignalling" equilibria in which very high types differentiate themselves from countersignalling high types by signalling.

The idea that signalling-like behavior need not be monotonically increasing in quality has appeared in several areas. Teoh and Hwang (1991) develop a model in which firms decide whether to immediately disclose favorable earnings information or wait for the information to be revealed by other sources. Waiting makes higher-quality firms look bad at first but eventually separates them from lower-quality firms, which face more immediate pressure to prove themselves. Bhattacharyya (1998) considers how large a dividend firms should declare and finds that a screening model predicts that, conditioned on earnings, higher-quality managers will declare lower dividends since they can use funds more efficiently than lower-quality managers. Fremling and Posner (1999) discuss how those with already high status may have lower marginal returns from signalling than those who are not so well regarded.[3] Hvide (1999) examines a labor market model in which education serves partly to inform workers of their true abilities and finds that only average types will choose to become educated. We differ from these analyses in following a standard signalling model exactly, with the sole exception of allowing for the presence of additional information on sender type. This added realism is sufficient to significantly expand the set of equilibria from a standard signalling game, allowing for nonmonotonic equilibria that are robust to standard refinements.

Countersignalling theory takes the intuition of signalling and shows how it can lead to quite different behavior than normally supposed, offering insight into phenomena that appear inconsistent with the standard signalling model. Of course, countersignalling is somewhat complex, and there remains the issue of whether economic agents are capable of such behavior. To help answer this question, we report results of an experimental test conducted in the fall of 1995. The experiments involved two games with three types of senders, high, medium, and low quality, and a binary signal. The first game is isomorphic to a standard signalling game and has a unique equilibrium in which high and medium types signal. The second game is identical to the first game, except extra, noisy information on types leads to the unique equilibrium involving countersignalling by high types. Experimental results tend to support the theory's predictions. From almost identical initial play in the two games, subject behavior diverged to a large amount of countersignalling by high types in the latter game and almost none in the former game.

[3] Our model supports such an argument in that high types benefit less from signalling because they are already partially separated from low types.

2. A simple example

■ Continuing the signalling literature's traditional emphasis on education, consider the following stylized example. A prospective employee who had good grades in high school is considering whether to mention her grades in a job interview. Because grading standards are weak, both medium- and high-productivity employees (Highs and Mediums) are known to have good grades, while only low-productivity employees (Lows) are known to have poor grades. Since lying about grades involves the chance of getting caught, the signal of mentioning good grades is costly to Lows but free to Mediums and Highs. In addition to this signal, the interviewer will receive from a former boss a recommendation regarding the prospective employee's abilities. Lows expect to receive bad recommendations from their old boss and Highs expect to receive good recommendations, while Mediums receive good or bad recommendations with equal probability.

What should an interviewee do? Without the recommendation, Mediums and Highs should clearly mention their good grades, since it costs them nothing and since the grades differentiate them from Lows. With the addition of the extra information as embodied by the recommendation, the situation is less obvious. Consider if the interviewer believes that only Mediums mention their grades. Then if Mediums don't mention their grades, they take the chance of either receiving a good recommendation and being thought of as a High or receiving a bad recommendation and being thought of as a Low. If Lows are sufficiently unproductive relative to Mediums and Highs, not mentioning grades is too risky. Highs face a different situation because they expect to receive a good recommendation. Since they need not worry about being perceived as a Low, they face a clear choice between being perceived as a Medium if they mention their grades and a High if they do not. Since receiver beliefs are consistent with sender strategies and sender strategies make sense given receiver beliefs, a countersignalling equilibrium exists in which Highs show off their confidence by not mentioning their grades.[4]

A numerical example may help illuminate this case. Assume that productivity is 400, 700, and 900 for Lows, Mediums, and Highs respectively, and that Lows and Highs are equally prevalent in the population. Given the interviewer's beliefs, Mediums can choose to receive either 700 by mentioning their grades or $(400+900)/2 = 650$ by deviating from the equilibrium and mimicking the Lows and Highs. Meanwhile, Highs are perfectly separated from Lows so they receive 900 by countersignalling versus only 700 by deviating and looking like a Medium. Finally, as long as lying about grades costs Lows at least 300, Lows do not gain from mimicking the Mediums, so a countersignalling equilibrium exists.

For simplicity, this example assumes that the signal of "bragging" about one's grades is free for both Mediums and Highs, but the results do not depend on this assumption. Hence this model would still apply if we were looking not just at the decision to report grades, but at the potentially costly choice of whether to get good grades in the first place. Countersignalling would still be an equilibrium even if signalling cost Mediums as much as 50 and cost Highs as little as *negative 200*, meaning that Highs would prefer to get good grades in a full-information environment. Note that countersignalling can break down not just if signalling is too attractive for Highs, but also if signalling is too expensive for Mediums, e.g., the grading standard makes it difficult for Mediums to get good grades. When signalling by Mediums becomes too expensive and they stop signalling in equilibrium, Highs can no longer separate themselves from Mediums by not signalling and must instead signal in order to differentiate themselves. Therefore an increase in signalling costs can actually induce Highs to start signalling.

Regarding the extra information embodied by the former boss's recommendation, the extremely dichotomous information structure simplifies the problem, but noisier information can still support a countersignalling equilibrium. In this example, even if Lows receive a good recommendation 25% of the time and Highs receive a bad recommendation 25% of the time, a

[4] A partial-pooling equilibrium is still possible in which both Mediums and Highs are believed to signal, but if Lows are sufficiently unproductive relative to Mediums and Highs and if the recommendations completely separate Lows and Highs, the equilibrium does not survive the Intuitive Criterion (Cho and Kreps, 1987). Refinements are discussed further in Section 3.

countersignalling equilibrium still exists. For an interviewee who doesn't mention grades, if a bad recommendation is observed the expected quality of the interviewee is $(3/4)400+(1/4)900 = 525$, while if a good recommendation is observed the expected quality is $(1/4)400 + (3/4)900 = 775$. Since Mediums expect good and bad recommendations with equal probability, they still expect to receive 650 if they countersignal versus 700 if they signal. Lows expect to receive a bad recommendation $3/4$ of the time and to receive a good recommendation $1/4$ of the time, so they expect to receive $(3/4)525 + (1/4)775 = 587.5$ by not signalling, giving them even less incentive to deviate than in the previous case. For Highs, quality will be estimated at $(1/4)525 + (3/4)775 = 712.5$ if they countersignal, so deviating is unprofitable and the countersignalling equilibrium still stands. Depending on the exact model parameters, even a little bit of extra information can disrupt the standard result that signals are nondecreasing in type.

In this example, interviewees faced a simple binary choice of mentioning their grades or not. While signalling decisions are often binary, in many cases a wider range of signals is available, e.g., how expensive a car one buys. In such cases it is less obvious that Highs will be willing to pool with Lows, since they have the extra option of breaking off and sending a higher signal that is not worthwhile for Mediums to mimic. The following section develops the theory for this case, showing that Highs can still choose to countersignal by pooling with Lows. In Section 4 we return to the simplest case of a binary signal with three types to report on an experimental test of countersignalling.

3. A theory of countersignalling

■ In this sender-receiver game, we allow for three sources of receiver information. First, there is common knowledge about the distribution of types that incorporates all the background information that both senders and receivers know. For instance, if it is common knowledge that all senders are in a certain age group, then the distribution of types is conditioned on this knowledge. Continuing to assume that there are "Low," "Medium," and "High" types, let the set of types be $Q = \{L, M, H\} \subset \mathbb{R}_+$, where $0 \leq L < M < H$ and where types are distributed according to the probability distribution $f(q)$.

Second, the sender sends a signal s in the set $S \subset \mathbb{R}_+$ that is observed by the receiver. The receiver observes this signal noiselessly but does not know which type sent the signal. This signal costs the sender $c(s, q)$, where c is increasing and convex in s and decreasing in q. To ensure there is some signal that everyone would be willing to send, we assume that $0 \in S$ and c satisfies $c(0, q) = 0$. Further, we assume the standard single-crossing property that $c_s(s, q) > c_s(s, q')$ for $q < q'$, i.e., not only is it less costly for higher types to send any given signal than it is for lower types, but the marginal cost of that signal is also less. The assumption that the marginal cost of signalling is always positive will be relaxed later.

Finally, and this is the unique aspect of the model, the receiver has extra, noisy information about the sender's type. This information is sent at no cost to the sender and is exogenous in the sense that sender actions cannot at this stage affect it. The sender knows that the receiver has this information but is unaware of exactly what the receiver knows. We model this information as a noisy exogenous signal, $x \in X$, distributed according to the conditional probability distribution $g(x \mid q)$. Assume that g has full support over X for any q.[5] The conditional distribution of the exogenous signal is common knowledge, but the actual value of x is not known to the sender at the time of sending the *endogenous* signal. In general, the exogenous signal can be thought of as a summary measure of all the other noisy information that the receiver will have about the sender at the time of making the signalling choice. To reduce confusion with the signal, s, we will refer to the noisy exogenous signal, x, as just "extra information."

The structure of the game is as follows. First, a sender is drawn randomly from the distribution of types. The sender then sends the endogenous signal without knowing what was or will be the

[5] The assumption of full support simplifies the discussion of out-of-equilibrium beliefs. When the support of g is less than full, extreme information structures can yield unique Intuitive Criterion countersignalling equilibria as in the simple example given in Section 2 and used in the experimental test in Section 4.

realized value of the extra information. Finally, the receiver observes both the extra information and the sender's signal. Given this information and her beliefs about sender signalling strategies, the receiver rewards the sender with the sender's expected quality.[6] This can be thought of as a reduced form of a game in which senders are workers and receivers are firms that simultaneously make wage offers.

Regarding the timing of signals, if all the available extra information is embodied in x and is known to both the sender and the receiver prior to sending the endogenous signal, then the model reduces to the standard signalling framework, where the distribution of types is given by $\hat{f}(q) = g(x \mid q)f(q)/\sum_{q' \in Q} g(x \mid q')f(q')$. Our assumption that the sender chooses s without knowing the realized value of x is therefore necessary for a countersignalling equilibrium. We believe this assumption to be innocuous in the sense that regardless of what is known prior to the choice of s, there is always some information that is unknown to the sender. For example, suppose that extra information, x, is observed by the sender and receiver prior to the sender's choice over s, but extra information y is unobserved by the sender. Given x, if y is informative about q, then y plays the exact same role as x in our model.

Except for a brief discussion of mixed-strategy equilibria later in this section, we consider only pure-strategy Nash equilibria, so a strategy is a mapping between types and signals. Let s_q represent the pure strategy of a sender of type q, and let the function $\mu(q \mid s, x)$ be a probability distribution representing receiver beliefs about which types q send observed signal s and information x. Receiver expectations of sender quality, given receiver beliefs and the observed signals, are

$$\sum_{q' \in Q} q' \mu(q' \mid s, x).$$

Assuming sender risk neutrality for simplicity, the gross of costs expected payoff to type q of sending signal s is the sender's expected perceived quality,

$$E_\mu[q' \mid s, q] = \int_{x \in X} \left(\sum_{q' \in Q} q' \mu(q' \mid s, x) \right) g(x \mid q) dx. \tag{1}$$

Definition 1. A pure-strategy perfect Bayesian equilibrium is given by a type-contingent strategy profile s_q and receiver beliefs $\mu(q \mid s, x)$, where

(i) $E_\mu[q' \mid s_q, q] - c(s_q, q) \geq E_\mu[q' \mid s', q] - c(s', q)$ for any $s' \in S$ and
(ii) for any $s \in S$, $\mu(q \mid s, x)$ is such that if $\{q' \mid s_{q'} = s\} \neq \emptyset$, then

$$\mu(q \mid s, x) = \frac{g(x \mid q)f(q)}{\sum_{\{q' \mid s_{q'} = s\}} g(x \mid q')f(q')}. \tag{2}$$

Condition (i) requires that agents choose signals as a best response to the receiver's beliefs. Condition (ii) requires that for any information set that can be reached on the equilibrium path, the receiver's beliefs are consistent with Bayes' rule and the equilibrium sender strategy.[7]

We follow the convention of calling a perfect Bayesian equilibrium a *signalling equilibrium* if s_q is strictly increasing in the sender's type. Any equilibrium in which s_q is strictly nonmonotonic will be called a *countersignalling equilibrium*. Note that in the initial motivating example (Section 2) and the later experimental test (Section 4), we use a binary signal so that the alternative to countersignalling is a *weak signalling equilibrium* in which s_q is weakly increasing in the sender's

[6] The signals are thereby assumed to play a purely informational role, having no effect on the sender's productivity or other valued attributes.

[7] Note that if g has less than full support, (ii) would have to be modified to read "... such that if there exists a $q \in \{q' \mid s_{q'} = s\}$ such that $g(x \mid q) > 0$, then..."

type and strictly increasing at only one point. Weak signalling equilibria can also survive in the richer signalling space we use in this theory section, but for a clear comparison with the signalling literature we restrict our attention to signalling equilibria and countersignalling equilibria.

As mentioned earlier, we require that the extra information, x, should be in some sense informative. First note that for x to have any information content in equilibrium, at least two types must send the same signal. Otherwise, with perfect separation, the extra information plays no role. A sender must believe that if she pools with senders of lower type, she will be rewarded more, on average, than them. That is, the sender may do worse than lower types *ex post* once the receiver has observed the available information, but the information is correct on average so that *ex ante* the sender does better in expectation.

To define this notion more precisely, we need to first provide some additional notation. Since we are only interested in pure-strategy equilibria, this assumption will be defined in terms of sets of agents, $\Lambda \subset Q$, who pool together.[8] For any nonempty Λ, let $\bar{q}_\Lambda(q)$ be a sender of type q's gross expected payoff, given that the receiver uses Bayes' rule and believes her to be of some type belonging to Λ. That is,

$$\bar{q}_\Lambda(q) = \int_{x \in X} \left(\sum_{q' \in \Lambda} q' \frac{g(x \mid q')f(q')}{\sum\limits_{q'' \in \Lambda} g(x \mid q'')f(q'')} \right) g(x \mid q)dx. \tag{3}$$

The term within the parentheses is the receiver's Bayesian estimate of the sender's quality having observed x. Integrating over all $x \in X$ yields a type-q sender's *ex ante* expected payoff from pooling with the agents in Λ. It is easy to see that if $\Lambda = \{q'\}$ for $q' \in Q$ (i.e., it is a singleton), then $\bar{q}_\Lambda(q) = q'$ for any $q \in Q$. That is, if q' is the only type sending some signal s, then upon observing s the receiver must believe that the sender is of type q'.

We will consider the conditional distribution, g, to be *informative* if and only if for any $\mid \Lambda \mid \geq 2$ and for any $q, q' \in Q$, whenever $q < q'$, then $\bar{q}_\Lambda(q) < \bar{q}_\Lambda(q')$. A sufficient condition for this to hold is that x and q are affiliated or, equivalently, that $g(x \mid q)$ satisfies the monotone likelihood ratio property. Note that types sending the same endogenous signal are imperfectly separated by the extra information, since g has full support. This implies that $\min \Lambda < \bar{q}_\Lambda(q) < \max \Lambda$ for all $q \in Q$ and $\mid \Lambda \mid \geq 2$.

□ **Equilibria.** In a signalling equilibrium, $\mathbf{s} = (s_L, s_M, s_H)$, perfect separation implies that each type's expected payoff is equal to her quality, $E_\mu[q' \mid s_q, q] = q$ for $q \in Q$. The distribution of the extra information, $g(x \mid q)$, therefore plays no role in equilibrium, so the standard result for signalling games with cost functions satisfying the single-crossing property still applies.

Proposition 1. Signalling equilibria always exist.

Note that the payoffs and signals in a signalling equilibrium are independent of the distribution of the extra information, $g(x \mid q)$. As we will see, this distribution plays a significant role in the partial pooling that occurs in a countersignalling equilibrium.

With only three types, a countersignalling equilibrium must have Lows and Highs pooling, so there are two candidate classes of pure-strategy countersignalling equilibria: u-shaped equilibria and hump-shaped equilibria. Since the former class can be ruled out by our informational assumptions,[9] all countersignalling equilibria must be in the latter class. Suppose that senders

[8] That is, suppose the receiver only knows that the agent belongs to the set Λ with priors based on f and may subsequently adjust those priors based on new information (i.e., x).

[9] Suppose $\mathbf{s}^* = (s^*, s_M^*, s^*)$ is a countersignalling equilibrium where $s^* > s_M^*$. Since $\mathbf{s}^*$ is an equilibrium, then both $\bar{q}_{\{L,H\}}(L) - M \geq c(s^*, L) - c(s_M^*, L)$ and $\bar{q}_{\{L,H\}}(M) - M \leq c(s^*, M) - c(s_M^*, M)$. Furthermore, since the cost function for Mediums is flatter than that for Lows (the single-crossing property), $s^* > s_M^*$ implies that $c(s^*, L) - c(s_M^*, L) > c(s^*, M) - c(s_M^*, M)$. However, this means that $\bar{q}_{\{L,H\}}(L) - M > \bar{q}_{\{L,H\}}(M) - M$, a contradiction since $\bar{q}_{\{L,H\}}(L) < \bar{q}_{\{L,H\}}(M)$.

play strategy $\mathbf{s}^* = (s^*, s_M^*, s^*)$ where $s^* < s_M^*$. Let μ describe beliefs that are Bayes consistent with playing $\mathbf{s}^*$. Then the expected gross payoff to sender q from signal s_M^* is

$$E_\mu[q' \mid s_M^*, q] = M$$

and the expected gross payoff to sender q from signal s^* is

$$E_\mu[q' \mid s^*, q] = \int_{x \in X} (\mu(L \mid s^*, x)L + \mu(H \mid s^*, x)H)g(x \mid q)dx.$$

Since Lows and Highs send the same signal s^* and since μ is Bayes consistent, $E_\mu[q' \mid s^*, q] = \bar{q}_{\{L,H\}}(q)$. Therefore, by assumption, $E_\mu[q' \mid s^*, L] < E_\mu[q' \mid s^*, M] < E_\mu[q' \mid s^*, H]$.

In a standard signalling model the difference in the gross returns from sending signals s_M^* and s^*, namely $M - E_\mu[q' \mid s^*, q]$, is unaffected by the sender type because $E_\mu[q' \mid s^*, q] \equiv E_\mu[q' \mid s^*]$. Since signalling costs are falling in the quality of the sender, if Mediums found it advantageous to send signal s_M^*, then so would Highs. In our framework, on the other hand, $M - E_\mu[q' \mid s^*, q]$ is falling in quality. Since the gains from signalling are lower for Highs than Mediums, Highs may choose to not signal, even though signalling costs are also lower.

Proposition 2. A countersignalling equilibrium exists if $\bar{q}_{\{L,H\}}(L)$ and $\bar{q}_{\{L,H\}}(M)$ are sufficiently small and $\bar{q}_{\{L,H\}}(H)$ is sufficiently large.

Proof. All proofs are in the Appendix.

In other words, the extra information must be such that Mediums will tend to look like Lows if they do not signal, but Highs will still tend to look like Highs if they do not signal. If Lows and Mediums are insufficiently separated, the single-crossing property ensures that Mediums can always find a signal that Lows do not want to mimic but that costs less than $M - \bar{q}_{\{L,H\}}(M)$, so Mediums will signal. And if Highs and Lows are sufficiently separated by the extra information, then Highs are better off not signalling than appearing to be Mediums. These restrictions on the extra information are illustrated more concretely in the following proposition. As long as the distributions $g(x \mid L)$ and $g(x \mid M)$ are sufficiently similar and the distributions $g(x \mid L)$ and $g(x \mid H)$ are sufficiently dissimilar, a countersignalling equilibrium exists.

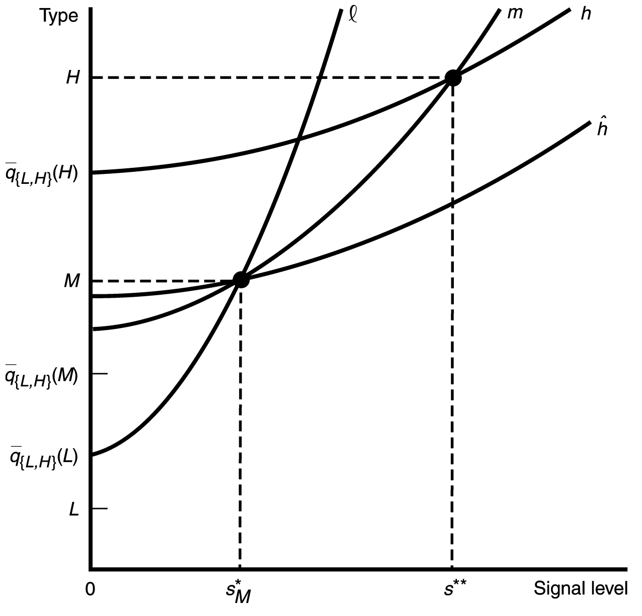
Proposition 3. A countersignalling equilibrium exists if $\int_{x \in X} \mid g(x \mid L) - g(x \mid M) \mid dx$ and $\int_{x \in X} g(x \mid L)g(x \mid H)dx$ are sufficiently small.

Figure 1 illustrates the countersignalling equilibrium $(0, s_M^*, 0)$. Level sets represent sender indifference between various payoff/signal combinations, where utility increases in a northwesterly direction. Following the single-crossing property, the sets are flattest for Highs and steepest for Lows, ensuring that the indifference curves of different types cross only once. The intercepts represent the utility payoffs of each indifference curve. Thus in this equilibrium, Highs get the greatest payoff, $\bar{q}_{\{L,H\}}(H)$, while Lows get the least, $\bar{q}_{\{L,H\}}(L)$. According to level set ℓ, Lows are just indifferent between sending signal s_M^* (pretending to be a Medium) and sending the equilibrium signal of zero (pooling with Highs). That is, s_M^* is the minimum signal that Mediums can send and deter Lows from mimicking them. The level set h represents the utility received by a High from playing according to equilibrium and not signalling. Highs are willing to pool with Lows as long as they get a greater payoff than from sending signal s_M^* and pretending to be a Medium, $\bar{q}_{\{L,H\}}(H) > M - c(s_M^*, H))$. This is true in our case, since indifference curve h is higher than $\hat{h}$. Finally, Mediums must prefer to send signal s_M^* to sending $s = 0$ and pretending to belong to $\Lambda = \{L, H\}$. This holds because the intercept of m (her equilibrium payoff) is greater than $\bar{q}_{\{L,H\}}(M)$.

As with the standard signalling model, ours is subject to multiple equilibria. A substantial literature has developed in an effort to "refine" away "undesirable" equilibria in signalling models (Banks and Sobel, 1987; Cho and Kreps, 1987; Cho and Sobel, 1990). Contrary to the standard

FIGURE 1

PARETO-DOMINANT COUNTERSIGNALLING EQUILIBRIUM



signalling framework, refinements such as the Intuitive Criterion, D1 and D2 are unable to rule out pooling and partial-pooling equilibria.[10] This can be seen from the simplest two-type model. Without extra information, Highs are indistinguishable from Lows in a pooling equilibrium, so they always have an incentive to break away and send a signal that Lows would never mimic, thereby implying that pooling cannot survive the Intuitive Criterion. With the extra information this is no longer true. Highs are stochastically separated from Lows even as they pool with them, so they are less willing to bear the cost of sending the minimum signal that Lows would never mimic. Moreover, the stochastic separation means that Lows gain less from pooling than when there is no extra information. This implies that if we consider the set of signals that Lows could never gain by sending, the minimum of this set is larger than when there is no extra information. Since extra information makes breaking the pooling equilibrium both less rewarding and more costly, a pooling equilibrium can survive the Intuitive Criterion if the stochastic separation is sufficient.

This same logic of pooling by Highs and Lows applies to our three-type case, except that it is even more costly for Highs to send a sufficiently large signal that Mediums would never mimic. As a result, we find that under conditions qualitatively similar to those given in Propositions 2 and 3, countersignalling equilibria continue to exist under the Intuitive Criterion, D1 and D2.[11] In particular, the conditions for the existence of the Pareto-dominant countersignalling equilibrium are qualitatively similar. Such countersignalling equilibria might be, in terms of welfare, more appealing than any signalling equilibrium. This is demonstrated formally for the Intuitive Criterion as follows.

[10] Given that the standard refinements cannot eliminate signalling equilibria under the standard model, such refinements will not eliminate signalling equilibria in our augmented framework, since such equilibria do not depend on any of the distributional information.

[11] Proofs are available at http://www.theo.to/counter/ or from the authors upon request. Note that the value of $\bar{q}_{\{L,H\}}(H)$ as shown in Figure 1 is the smallest such value for which the countersignalling equilibrium depicted survives the Intuitive Criterion, D1 and D2.

Proposition 4. If the Pareto-dominant countersignalling equilibrium survives the Intuitive Criterion, it Pareto dominates all signalling equilibria. In particular, every type of sender is strictly better off under the Pareto-dominant countersignalling equilibrium.

The argument is roughly as follows. Suppose that the Pareto-dominant countersignalling equilibrium does not Pareto dominate the Pareto-dominant signalling equilibrium (the Riley (1975) equilibrium). Since Lows benefit from pooling with Highs, and since Mediums can then send a lower signal to successfully ward off Lows, it must be the Highs who are worse off. However, suppose that Highs deviate and send their equilibrium signal from the Riley equilibrium. With probability 1 they would be thought to be Highs, since Mediums would never be willing to send this signal. Since their signalling payoff is greater than their countersignalling payoff, Highs have an incentive to deviate from the countersignalling equilibrium by playing according to the signalling equilibrium. So if the countersignalling equilibrium does not Pareto dominate the Riley equilibrium, it must not pass the Intuitive Criterion.

This can be understood with the help of Figure 1. First notice that Lows are better off under the Pareto-dominant countersignalling equilibrium because $\bar{q}_{\{L,H\}}(L) > L$. It then follows that Mediums are also better off because a signal sufficient to deter Lows from imitating does not need to be as high as under the Riley equilibrium ($s_M^* < s_M$). Finally, note that signal s^{**} is the minimal signal that a High could send that would deter a Medium from imitating but would yet be sufficient to convince the receiver that the sender is indeed a High. It is straightforward to see that $s^{**} < s_H$ so that it must be the case that Highs are strictly better off under countersignalling than under signalling. In other words, all senders get a higher payoff under the Pareto-dominant countersignalling equilibrium than they do under the Riley equilibrium.

Although a countersignalling equilibrium that survives the Intuitive Criterion must Pareto dominate the Riley equilibrium, the converse does not hold. That is, a Pareto-dominant countersignalling equilibrium that Pareto dominates the Riley equilibrium does not necessarily survive the Intuitive Criterion. To see this, consider again Figure 1. Note that $\bar{q}_{\{L,H\}}(H)$ in the figure is the minimum level such that the countersignalling equilibrium survives the Intuitive Criterion—if it were any lower, under the best possible beliefs, Mediums would have an incentive to send signal s^{**}. Suppose that $\bar{q}_{\{L,H\}}(H)$ is slightly lower. The countersignalling equilibrium still Pareto dominates the Riley equilibrium. But since a signal slightly higher than s^{**} would be sufficient for a Medium to convince the receiver that she is an H, it does not survive the Intuitive Criterion.

In practice, Proposition 4 might overstate the efficiency of countersignalling. We have assumed the receiver is risk neutral, but if the receiver is risk averse or benefits from matching senders to particular jobs based on their quality, the loss in information to the sender in the countersignalling equilibrium might exceed any cost savings to the senders. As discussed below, inefficiencies can also result if signalling is to some extent a desirable activity.

□ **Extensions.** In the first three of the following subsections, let $\mathbf{s} = (0, s_M, s_H)$ and $\mathbf{s}^* = (0, s_M^*, 0)$ represent the Riley equilibrium and the Pareto-dominant countersignalling equilibrium.

Productive signalling. Although the literature often emphasizes the wasteful nature of signalling, many forms of signalling are, in moderation, productive or otherwise desirable. For instance, while education may be excessive in a signalling equilibrium, it is often a preferred activity in moderation.[12] When signalling is to some extent desirable, countersignalling by Highs might be inefficient because of insufficient signalling. This is the case with the binary signal model used in the experiment.

To illustrate the point with a continuous signal, suppose we relax the condition that signalling costs are strictly increasing in the signal. In particular, assume that costs initially decrease from zero for Highs but eventually increase. For Lows and Mediums the cost structure is unchanged. If signalling costs do not decrease too rapidly for Highs, the equilibrium $(0, s_M^*, 0)$ still exists even

[12] Even in excess there might be positive externalities to education and other signalling activities that make more signalling socially efficient.

though in a perfect-information environment Highs would choose a strictly positive signal. In other words, whereas information asymmetry leads to wasteful behavior in a signalling equilibrium, information asymmetry can lead to wasteful avoidance of desirable behavior in a countersignalling equilibrium.

Bounded signals. So far we have assumed that the signalling range has no upper bound. Although in many cases this might be quite reasonable, it might be more realistic in other cases to include an upper bound on the highest signal that can be sent, e.g., the best signal that a high school student can send is to get straight A's. Consider if there is some maximum signal $\bar{s}$ so that $S = [0, \bar{s}]$. If $\bar{s} < s_H$, then the signalling equilibrium cannot exist. But if $\bar{s} \geq s_M^*$, then the countersignalling equilibrium still exists. Thus, by eliminating the possibility for a signalling equilibrium, putting an upper limit on the signal can be considered conducive to countersignalling. Highs cannot signal their capabilities relative to Mediums by sending a higher signal, so the only alternatives are countersignalling equilibria and other partial-pooling or pooling equilibria.

Alternative equilibria. Real-world signalling behavior may be more complicated than the pure-strategy equilibria we have derived in our simple three-type example. For instance, even in situations conducive to countersignalling, some high types may be observed to be countersignalling while others may be observed to be signalling. Three means of getting more complicated signalling behavior are (i) to add more types, (ii) to look at mixed-strategy equilibria, or (iii) to add a slightly more complicated information structure. We briefly consider each of these possibilities in turn.

Suppose there is a fourth type, $H^+ \geq H$, for which signalling is completely costless. This modification can yield a "counter-countersignalling" equilibrium where L, M, and H types play according to $\mathbf{s}^*$ and type-H^+ agents send an arbitrarily large signal. The presence of H^+ types has no effect on equilibrium beliefs over L, M, and H types, but a sufficiently large signal, $s_{H^+}^*$, will deter imitation by any type even under beliefs that survive the Intuitive Criterion, D1 and D2. Obviously, less-extreme cost structures will yield yet other types of counter-countersignalling behavior. For example, it may be that rather than sending a higher signal, there may be equilibria where H^+ types pool with M's.

Returning to the three-type example, now consider the possibility that senders play mixed strategies or that some proportion of each type plays different strategies. In particular, consider the mixed-strategy profile where Lows and Mediums and $1 - \Delta$ of the Highs play according to $\mathbf{s}^* = (0, s_M^*, 0)$ and the remaining Δ of the Highs send a signal, $\dot{s}_H^*$, at which they get H and are indifferent between sending 0 and $\dot{s}_H^*$. Given that it is more costly for Mediums to signal, they will be unwilling to send signal $\dot{s}_H^*$. Since fewer high types are now pooling with the low types, this will have the effect of reducing $\bar{q}_{\{L,(1-\Delta)H\}}(q)$ for all $q \in Q$. Provided that $\bar{q}_{\{L,(1-\Delta)H\}}(H) \geq M - c(s_M^*, H)$ and $\bar{q}_{\{L,(1-\Delta)H\}}(M) \leq M - c(s_M^*, M)$, this strategy profile is clearly an equilibrium. Furthermore, if $\bar{q}_{\{L,(1-\Delta)H\}}(H)$ is sufficiently large, $\mathbf{s}^*$ survives the Intuitive Criterion, D1 and D2. Notice that when pure-strategy countersignalling equilibria exist, there is in general a continuum of Δ's with equilibria where some Highs signal and some countersignal.

Finally, note that more complicated signalling patterns can also arise when there are multiple sources of extra information. Suppose, as discussed earlier, that there are two sources of extra information, x and y. The former is observed by both the sender and receiver and the latter is observed only by the receiver. In this case, for each $x \in X$, the distribution of types is $\hat{f}(q) = g(x \mid q)f(q)/\sum_{q' \in Q} g(x \mid q')f(q')$ and y plays the role of the extra information in our model. In other words, for each realization of x, a different game is played, so that the same type q might signal or countersignal depending on the realization of x and on the particular equilibria in the game corresponding to that realization of x.[13]

Countersignalling with a continuum of types. When types form a continuum and signals are continuous, nonmonotonicities could arise in a variety of forms. We present a simple example in

[13] The role of fully observed information in allowing for different equilibria conditional on the information is analyzed by Spence (1973a) in the context of a regular signalling game.

which types of highest and lowest quality send a zero signal while types within an intermediate range send the same signals as in the fully separating Riley equilibrium.[14] In particular, assume that types are distributed uniformly over the unit interval, $Q = [0, 1]$, and that $X = \mathbb{R}$ and $x = q+\varepsilon$, where ε is a random variable distributed normally with zero mean and standard deviation 1/4. Consistent with the single-crossing property, let the cost function be $c(q, s) = s/q^3$.

In a separating equilibrium each type is believed to send a unique signal and the extra information has no impact. Representing this mapping from signals to receiver inferences of type by $\hat{q}(s)$, the return to a signal is then $\hat{q}(s) - s/q^3$. Maximizing with respect to s gives $d\hat{q}(s)/ds = 1/q^3$. In equilibrium, beliefs are consistent with actions, so $\hat{q}(s) = q$, implying $q^3 dq = ds$. Integrating gives the family of solutions $s = q^4/4 + K$. The worst that the receiver can believe about a type sending a 0 signal is that they are of type $q = 0$, so type $q = 0$ never benefits from sending a positive signal. Therefore the Riley equilibrium $s = q^4/4$ is the only perfect Bayesian separating equilibrium.

We are interested in a countersignalling equilibrium where there are two types $0 < q_a < q_b < 1$ such that $s_q^* = q^4/4$ for $q \in [q_a, q_b]$ and $s_q^* = 0$ for $q < q_a$ and $q > q_b$. Since the distribution of types is a continuum, let $\mu(q \mid s, x)$ represent a probability measure in this section rather than a density function. Bayes-consistent receiver beliefs for $s = 0$ and x are therefore

$$d\mu(q \mid 0, x) = \frac{\phi(4(q-x))}{\int_0^{q_a} \phi(4(q'-x))dq' + \int_{q_b}^1 \phi(4(q'-x))dq'},$$

where $\phi(\cdot)$ represents the probability density function of a standard normal distribution. For $s \in (0, 1/4]$ we assume $\mu((4s)^{1/4} \mid s, x) = 1$, just as in the Riley equilibrium. Since not all signals in this range are actually sent in the countersignalling equilibrium, we are thereby assuming that if a signal is observed that would not be sent in the countersignalling equilibrium, the receiver believes it was sent by the type that would have sent it in the Riley equilibrium. Finally, for $s > 1/4$, let $\mu(1 \mid s, x) = 1$. Given these beliefs, the expected gross payoff to sender q from signal $s = 0$ is

$$E_\mu[q' \mid 0, q] = \int_{-\infty}^{\infty} \left(\int_0^{q_a} q' d\mu(q' \mid 0, x) dq' + \int_{q_b}^1 q' d\mu(q' \mid 0, x) dq' \right) \phi(4(x-q))dx.$$

The conditions for the marginal types to be indifferent are

$$E_\mu[q' \mid 0, q] - c(0, q) = q - c(q^4/4, q) \qquad \text{for } q = q_a, q_b.$$

Solving numerically, one solution is $q_a \approx 0.521$ and $q_b \approx 0.961$. Further calculations confirm types $q < q_a$ and $q > q_b$ prefer $s = 0$ to $s = q^4/4$, and types $q_a < q < q_b$ prefer $s = q^4/4$ to $s = 0$. The signal level stays at zero for $q < q_a$ but then jumps up to track the Riley equilibrium over the range $[q_a, q_b]$ before falling back to zero for $q > q_b$. Note that the payoff from signalling, $q - c(q^4/4, q) = 3q/4$, and the payoff from not signalling, $E_\mu[q' \mid 0, q]$, are both increasing in type. For low q the payoff from signalling approaches zero, while the payoff from not signalling is always strictly positive because low types are partially pooling with higher types. As q increases toward q_a, the payoff from signalling keeps rising at a constant rate, while the payoff from not signalling rises only slowly because most of the nonsignallers are low types. Within the signalling range $[q_a, q_b]$ the payoff from signalling continues to increase steadily, but the gains from not signalling start to accelerate because the chance of being confused with a low type falls. For types $q > q_b$ the odds of such a mistake are sufficiently small that they choose to countersignal. High types not only save costs by countersignalling, but since $E_\mu(q \mid 0, q_b) \approx .728 > q_a$, they are, in expectation, estimated to be of higher quality than many types sending a strictly positive signal.

[14] This example is based on a suggestion by Barry Nalebuff.

4. A test of countersignalling

■ To investigate whether agents can countersignal, we ran a simple experiment with two cells, one corresponding to a standard signalling game (the S cell) and the other to a countersignalling game (the C cell). We use a three-type model closely related to the example in Section 2.

□ **Description of the game.** Both the S and C cells share the same basic structure. We motivated the game to the subjects as an education model in which students signal their skill levels to firms. There are three types of student: High, Medium, and Low skill level. They signal in two ways: by grades, which they choose, and by test scores, which are exogenous and have a random component. After students have signalled, they are hired by competitive risk-neutral firms, so each student receives a wage equal to his expected productivity, conditional on his grade and test score. The role of the firms is suppressed in our experiment; their role is played by computer rather than by human subjects.[15]

The parameters used in the game are shown in Table 1. The population of students consists of 4 Highs, 8 Mediums, and 4 Lows.[16] Grade is a binary choice, either G (good) or B (bad). A bad grade is costless, while the cost of a good grade varies inversely with skill level and in the case of Highs is negative, i.e., Highs actually receive a direct benefit from signalling. Test scores are also binary, either P (pass) or F (fail). Test scores do not depend directly on grades. In the C cell the probability of passing is increasing in skill level, while in the S cell the probability is .5, irrespective of skill level.

Even though the exogenous signal is still present in the S cell, it is completely uninformative; there is no difference—even probabilistically—in the extra information sent by the different types of student. This game thus reduces to a standard signalling model in which higher-quality types signal to distinguish themselves from lower-quality types; the unique Nash equilibrium outcome of the S cell has all Highs and Mediums choosing a good grade and none of the Lows doing so. In contrast, the extra information in the C cell makes this a countersignalling environment. Lows always fail the exam and Mediums expect to fail the exam half the time, so Mediums can use good grades to differentiate themselves from Lows. Highs need not distinguish themselves from Lows, since Highs always pass and Lows always fail. Instead, they are concerned with being mistaken for those Mediums who pass. Since Mediums earn good grades, Highs react by earning bad grades even though they would prefer a good grade in a complete-information environment. In the unique equilibrium, Mediums choose good grades while Highs and Lows choose bad grades.

Our design makes the test of countersignalling difficult in two ways. First, we test for countersignalling when Highs have negative signalling costs, i.e., they receive a bonus for signalling, implying they would always signal in a perfect-information environment. Second, we give the games a somewhat normative context in which signalling is described as getting a "good grade" and not signalling as getting a "bad grade."

□ **Experimental procedures.** The experiment consisted of four S sessions and four C sessions. Subjects were mostly undergraduates at the University of Pittsburgh. Sessions lasted for roughly 90 minutes and consisted of 1 practice round and 12 rounds, except for one S session that, due to time constraints, consisted of 1 practice round and 10 rounds.[17] Subjects were not told how many rounds would be played, though they probably had some idea of when they were close to the end of the game because they were told the experiment would last no longer than 90 minutes. The experiment was conducted with pen and paper. Instructions were read aloud to subjects, and a table similar to Table 1 (but with only the information concerning the cell they were in) was

[15] This simplification saves costs and reduces strategic uncertainty for the senders. A disadvantage is that our experiment tests whether senders countersignal, but not whether receivers recognize countersignalling. Note that the appropriate equilibrium concept is now Nash equilibrium, since all players are choosing simultaneously.

[16] Since the only decision-making agents will be the students, we use "student" and "player" interchangeably.

[17] Keeping the number of rounds small has the advantages that subjects have time to think about their decisions and that payoffs per decision are relatively high.

TABLE 1 Characteristics of Player Types

Player Type (Skill Level)	Number of Type	Cost of Good Grade	% Passing Test S Cell	C Cell	Productivity
High	4	−25	50	100	900
Medium	8	+25	50	50	700
Low	4	+350	50	0	400

written at the front of the room. Subjects were given record sheets with spaces to write for each round their skill level, grade, test score, salary (called "gross payoff"), cost of earning a good grade,[18] and net payoff. In each round, each subject drew 1 of 16 slips of paper, on which was printed a skill level and test score, and a space for subjects to write their choice of grade. The slips of paper were prepared in advance and were repeatedly folded and sealed so that test scores could not be seen without breaking the seal. Skill levels and test scores were block-randomly assigned to the slips of paper, so that, in the S cell for example, in each round there were exactly four Mediums who passed the test, two Lows who failed the test, and so on.

In each round, each subject copied her skill level onto her record sheet, chose her grade, and wrote this grade on her record sheet and on the slip of paper. After this was done, a monitor came to the subject's desk and watched her break the seal, revealing her test score. The subject wrote her test score on her record sheet and the monitor collected the slip of paper. When all the slips had been collected, the distribution of skill levels and the salary, rounded up to the next dollar, corresponding to each (grade, test-score) pair were posted at the front of the room. Examples of this posted information are given in Table 2. Subjects then wrote their salaries on their record sheets and calculated and recorded their net payoffs. The next round then began. The posted information remained posted until it was replaced by information from the following round.

At the end of the session, one of the nonpractice rounds was randomly selected from those played, and subjects were paid in cash their net payoffs from that round at the exchange rate of 100 points/$1.00, in addition to a $5.00 participation fee. Average earnings were approximately $11.00.

□ **Experimental results.** Figures 2 and 3 show the relative frequencies of good grades in the two cells.[19] Early-round play is very similar in the two cells, but that play begins to diverge thereafter as Highs choose good grades less and less frequently in the countersignalling cell. Mediums in the signalling cell increase the frequency of choosing a good grade somewhat, with no such increase in the countersignalling cell. Lows also appear to choose good grades less and less frequently in the countersignalling cell, but this difference is slight.

Table 3 reports the frequency with which players in the two cells chose G in early and in late rounds.[20,21] Thus, at least in early rounds, players do not seem to behave in accordance with the equilibrium predictions. However, some aspects of play in later rounds are consistent with

[18] Because Highs have a negative "cost" of earning a good grade, we used the phrase "bonus or penalty" in the experiment.

[19] The raw data and instructions from the experiment are available at http://www.theo.to/counter/ or from the authors upon request.

[20] Play is remarkably similar across the four S sessions and, for the most part, is similar across C sessions. The one exception is Highs in the C cell: the frequency of good grades is 58.3%, 68.8%, 79.2%, and 95.8% in the four C sessions, while no other type in either cell has a range of 20 percentage points or more. According to one-tailed permutation tests (Siegel and Castellan, 1988) on the session-level data, there are no significant differences (at even the 10% level) in early-round frequencies of G between the S and C cells.

[21] We use the permutation test because, unlike the commonly used Wilcoxon-Mann-Whitney test, it makes no auxiliary assumptions about underlying population distributions that could lead to rejection of the null hypothesis based on differences in variances or other higher moments. Siegel and Castellan (1988) discuss this issue further and describe the nonparametric tests we use.

TABLE 2 Sample of Post-Round Information Given to Subjects

	Grade			
	G		*B*	
Panel A: Signalling Cell				
Test score				
P	Number High	2	Number High	0
	Number Medium	4	Number Medium	0
	Number Low	0	Number Low	2
	Salary	767	Salary	400
F	Number High	2	Number High	0
	Number Medium	4	Number Medium	0
	Number Low	0	Number Low	2
	Salary	767	Salary	400
Panel B: Countersignalling Cell				
Test score				
P	Number High	0	Number High	4
	Number Medium	4	Number Medium	0
	Number Low	0	Number Low	0
	Salary	700	Salary	900
F	Number High	0	Number High	0
	Number Medium	4	Number Medium	0
	Number Low	0	Number Low	4
	Salary	700	Salary	400

the theory's predictions. Recall that the Nash equilibrium predicts Highs should choose *G* more often in the S cell than in the C cell, while play of Mediums and Lows should be the same in both cells. In rounds 10–12 Highs are far more likely to play *G* in the S cell than in the C cell, and this difference is significant (permutation test, $p < .05$) However, Mediums and Lows also play *G* significantly more often in the S cell than in the C cell (permutation test, $p < .05$).[22]

Because not only Highs but also Mediums choose *G* more often in the C cell than in the S cell, differences between the play of Highs and that of Mediums in the C cell are smaller than one would hope, even in late rounds of the experiment. (Differences in the S cell are even smaller, but that is exactly the equilibrium prediction.) A χ^2 test of the difference between the play of Highs and that of Mediums in round 12, using the individual-level data, gives a p-value of about .12, which is suggestive but not significant at standard levels. A robust rank-order test, using the individual-level data from rounds 10–12, gives a p-value of .0643.[23] Using session-level data, rather than individual-level data, yields no significant differences between the play of Mediums and that of Highs in the C cell.

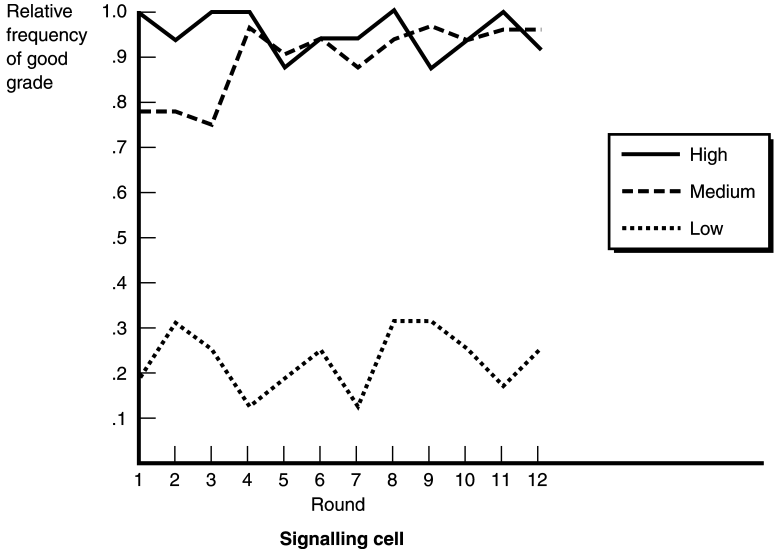
□ **Discussion.** The only difference between our S and C cells is that in the S cell the extra information is uninformative, while in the C cell it is informative. There is no difference in

[22] Lower choices of *G* by Mediums and Lows in the C cell may reflect expected-payoff differences. For Mediums, *G* and *B* earn 742 and 500 (respectively) in the S cell, and 675 and 660 in the C cell, so the incentive to choose *G* is much higher in the former. Similarly, for Lows, *G* and *B* earn 365 and 400 in the S cell, and 290 and 400 in the C cell.

[23] To implement this test, as well as to eliminate one possible source of dependence among data points, play over each player and type was averaged. Specifically, if the player with ID# 6 was a Medium type in rounds 11 and 12, and played *G* in 11 and *B* in 12, she was listed as having chosen *G* with relative frequency .5. If the player with ID# 7 was a Medium type in only round 10, and played *B*, he was listed as having chosen *G* with relative frequency 0.

FIGURE 2

PLOT OF RELATIVE SIGNALLING FREQUENCY: SIGNALLING CELL



early-round play between the cells, but eventually differences emerge in the direction predicted by countersignalling theory, though not always significant at standard levels. The patterns of behavior observed can best be described with the following "learning" story. In the S cell, bad grades are a dominant strategy for Lows; by choosing bad grades, they earn at least 400, while good grades earn them at most 384.[24] Indeed, we see that Lows, for the most part, quickly learn to get bad grades. Once most Lows are choosing bad grades, Mediums and Highs do best by earning good grades, and they learn this quickly, too. Play thus moves quickly toward the equilibrium.[25]

In the C cell, bad grades are again dominant for Lows, and the payoff differential is even larger—now, good grades earn them at most 290. Again, they quickly learn to choose bad grades. Once most of the Lows are choosing bad grades, good grades become a best response for Mediums, and they indeed tend to choose good grades. Once Mediums are choosing good grades, Highs do better by choosing *bad* grades. While the experiment never reaches the point where all Highs choose bad grades, by the final round slightly more than half of them do so, while hardly any Highs in the S cell ever choose bad grades.

One reason for the slow convergence of play in the C cell to the countersignalling equilibrium may be the incentives Highs face when play is not in equilibrium. As shown in Figure 3, Highs begin the session by choosing good grades. Given the belief that the other three Highs are going to continue choosing good grades, the fourth High should choose bad grades only if at least seven of the Mediums choose to earn good grades, but the fraction of Mediums choosing good grades in the C cell is rarely this high (only in 18 rounds out of 48). But as soon as one High is choosing bad grades, the incentive for the remaining Highs to also countersignal is stronger.[26]

5. Conclusion

■ Addition of noisy information about type to a standard signalling model allows for equilibria in which medium types signal to distinguish themselves from low types but high types do not.

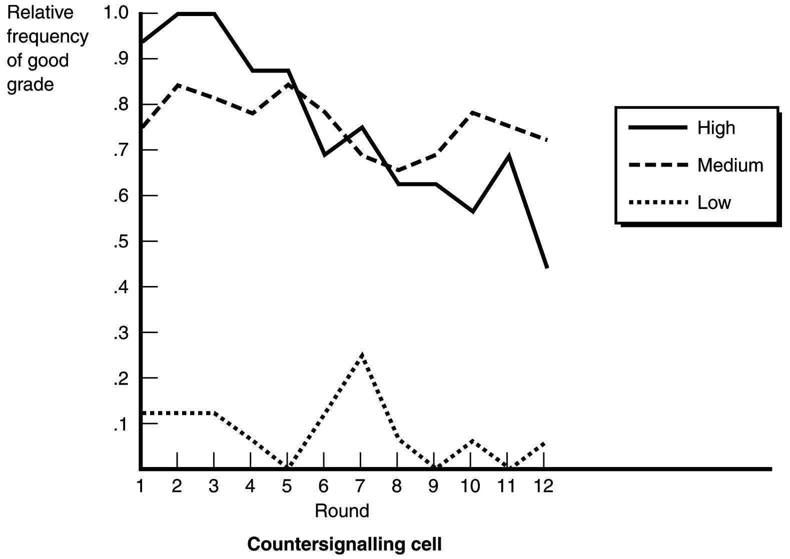
[24] This can happen if it is the only Low choosing G and passing the test. If all Highs choose G and all Mediums choose B, then this Low will be grouped with two Highs and no Mediums and will thus receive a salary of 734.

[25] The small but consistent proportion of G choices by Lows may reflect failure to consider the effect of their own behavior. While a Low optimally chooses B, earning a net payoff of 400, the salary of 767 to the group choosing G may be tempting. However, switching to G reduces that group's salary to 715 and the net payoff to 365.

[26] This "positive feedback" might explain the higher variance across sessions in play of the Highs in the C cell.

FIGURE 3

PLOT OF RELATIVE SIGNALLING FREQUENCY: COUNTERSIGNALLING CELL



Such countersignalling by high types can be seen as a sign of confidence. Signalling proves the sender is not a low type but also reveals the sender's insecurity that she would be perceived as such if she did not signal. In contrast, countersignalling indicates the sender's faith that whatever other information the receiver has on her will probably be consistent with her being of high quality.

Countersignalling captures the intuition that many of the highest-quality senders may be understated rather than overstated in their signalling behavior. As a result, countersignalling equilibria can invert a number of the main implications of signalling models. Whereas signalling equilibria can be inefficient because of excessive signalling, countersignalling equilibria may be inefficient because of inadequate signalling. While signalling equilibria can play an informational role in increasing the efficiency of receiver estimates of type, countersignalling equilibria may lower the efficiency of these estimates. And while higher costs tend to reduce signalling in a

TABLE 3 Aggregate Early- and Late-Round Frequency of Signalling

	C Sessions			S Sessions		
	High	Medium	Low	High	Medium	Low
Round 1	15/16 (.938)	24/32 (.750)	2/16 (.125)	16/16 (1.000)	25/32 (.781)	3/16 (.188)
Rounds 1–3	47/48 (.979)	77/96 (.802)	6/48 (.125)	47/48 (.979)	74/96 (.771)	12/48 (.250)
Rounds 10–12	27/48 (.562)	72/96 (.750)	2/48 (.042)	38/40 (.950)	76/80 (.950)	9/40 (.225)
Round 12	7/16 (.438)	23/32 (.719)	1/16 (.062)	11/12 (.917)	23/24 (.958)	3/12 (.250)
Equilibrium prediction	.000	1.000	.000	1.000	1.000	.000

signalling model, a limited increase in costs can lead to more signalling in a countersignalling model.

The extra information in a countersignalling model can allow a wide range of pooling and partial-pooling equilibria to survive standard refinements that leave only a unique, separating equilibrium in a signalling model. Both signalling and countersignalling equilibria may coexist, along with mixed-strategy equilibria where some high types signal and others countersignal. When there are more than three types, counter-countersignalling equilibria are also possible in which the very highest types signal to separate themselves from countersignalling high types.

Since countersignalling is more complicated behavior than signalling, the question of whether economic agents can countersignal was tested with a two-cell experiment in which extra information on sender type was available. In one cell the extra information was completely uninformative and signalling by medium and high types was the unique Nash equilibrium. In the other cell the extra information was partially informative and the unique Nash equilibrium involved countersignalling by high types even though high types had a negative cost to signalling. The experimental results confirm that adding noisy exogenous information on types to signalling games can affect behavior in directions consistent with the predictions of countersignalling theory. Countersignalling by high types was rare in the signalling cell but was the most common choice by the last period of the countersignalling cell.

Appendix

■ Proofs of Propositions 2, 3, and 4 follow.

Recall that $\bar{q}_{\{L,H\}}(q) = E_\mu[q' \mid s^*, q]$ is the expected gross payoff of a type-q individual whom the receiver believes to belong to $\{L, H\}$. Let $\hat{s}_L^*$ solve $\bar{q}_{\{L,H\}}(L) - c(\hat{s}_L^*, L) = L$. Since $\bar{q}_{\{L,H\}}(L) > L$, $\hat{s}_L^* > 0$. Now for $s^* \geq 0$, let $\tilde{s}_M^*(s^*)$ and $\hat{s}_M^*(s^*)$ solve $\bar{q}_{\{L,H\}}(L) - c(s^*, L) = M - c(\tilde{s}_M^*, L)$ and $M - c(\hat{s}_M^*(s^*), M) = \bar{q}_{\{L,H\}}(M) - c(s^*, M)$. Note that $\tilde{s}_M^*(s^*)$ is the minimum signal required to deter Lows from imitating the Mediums and $\hat{s}_L^*$ and $\hat{s}_M^*(s^*)$ are the maximum signals that Lows and Mediums are willing to send before they would prefer to send some alternative signal.

Lemma A1. A countersignalling equilibrium exists if and only if there is an s^* and an s_M^* such that $s^* \in [0, \hat{s}_L^*]$, $s_M^* \in [\tilde{s}_M^*(s^*), \hat{s}_M^*(s^*)]$, and $\bar{q}_{\{L,H\}}(H) - c(s^*, H) \geq M - c(s_M^*, H)$.

Proof. ($\Leftarrow$) For any $x \in X$, let beliefs be given by $\mu(L \mid s, x) = 1$ whenever $s \notin \{s^*, s_M^*\}$. Let $\mu(L \mid s^*, x) = g(x \mid L)f(L)/(g(x \mid L)f(L) + g(x \mid H)f(H))$, $\mu(H \mid s^*, x) = 1 - \mu(L \mid s^*, x)$ and $\mu(M \mid s_M^*, x) = 1$. These beliefs clearly satisfy (ii) of the definition of a PBE. Thus we need to show that each agent's best response is to follow his prescribed strategy. Obviously no type has an incentive to choose $s \notin \{s^*, s_M^*\}$, since he would receive a payoff of $L - c(s, q)$, which is no greater than the payoff L he would get by choosing $s = 0$.

Now, since $s^* \leq \hat{s}_L^*$, $E_\mu[q' \mid s^*, L] - c(s^*, L) \geq \bar{q}_{\{L,H\}}(L) - c(\hat{s}_L^*, q) = L$, it is individually rational for a type-L player to choose s^*. Since $s_M^* \geq \tilde{s}_M^*(s^*)$, it follows that $E_\mu[q' \mid s^*, L] - c(s^*, L) = M - c(\tilde{s}_M^*(s^*), L) \geq M - c(s_M^*, L)$, so no L-type individual has an incentive to choose $s = s_M^*$.

Since $s_M^* \leq \hat{s}_M^*(s^*)$, $M - c(s_M^*, M) \geq M - c(\hat{s}_M^*(s^*), M) = \bar{q}_{\{L,H\}}(M) - c(s^*, M)$, no type-$M$ individual has an incentive to choose $s = s^*$.

Finally, in order for Highs to be willing to send signal s^*, they must get at least as much as they would if they imitated the Mediums (i.e., $\bar{q}_{\{L,H\}}(H) - c(s^*, H) \geq M - c(s_M^*, H)$).

($\Rightarrow$) Follows by reversing the previous arguments. *Q.E.D.*

Proof of Proposition 2. We already know the interval $[0, \hat{s}_L^*]$ is nonempty, so it remains to be shown that if $\bar{q}_{\{L,H\}}(L)$ and $\bar{q}_{\{L,M\}}(M)$ are sufficiently small, then $[\tilde{s}_M^*(s^*), \hat{s}_M^*(s^*)]$ is nonempty, and if $\bar{q}_{\{L,M\}}(H)$ is sufficiently large, then $\bar{q}_{\{L,H\}}(H) - c(s^*, H) \geq M - c(s_M^*, H)$.

First, note that $\tilde{s}_M^*(s^*) > 0$ exists if and only if $\bar{q}_{\{L,H\}}(L) - c(s^*, L) < M$. This is true if and only if $\bar{q}_{\{L,H\}}(L)$ is sufficiently small.

Next, since we are only looking for sufficient conditions, take $s^* = 0$. By definition, $\tilde{s}_M^*(0)$ and $\hat{s}_M^*(0)$ satisfy $c(\tilde{s}_M^*(0), L) = M - [\bar{q}_{\{L,H\}}(L) - c(0, L)]$ and $c(\hat{s}_M^*(0), M) = M - [\bar{q}_{\{L,H\}}(M) - c(0, M)]$. If g is such that $\bar{q}_{\{L,H\}}(M)$ is "close" to $\bar{q}_{\{L,H\}}(L)$, then $c(\tilde{s}_M^*(0), L) \approx c(\hat{s}_M^*(0), M)$. Since $c(s, M) < c(s, L)$, it follows that $\tilde{s}_M^*(0) < \hat{s}_M^*(0)$. That is, when $\bar{q}_{\{L,H\}}(M)$ is sufficiently small (i.e., close to $\bar{q}_{\{L,H\}}(L)$), the interval $[\tilde{s}_M^*(0), \hat{s}_M^*(s^*)]$ is nonempty.

Finally, given some $s_M^* \in [\tilde{s}_M^*(0), \hat{s}_M^*(0)]$, it is clear that when $\bar{q}_{\{L,H\}}(H)$ is sufficiently close to H, $\bar{q}_{\{L,H\}}(H) - c(0, H) \geq M - c(s_M^*, H)$. *Q.E.D.*

Proof of Proposition 3. Let $\int_{x \in X} g(x \mid L)g(x \mid H)dx < \varepsilon_1$ and $\int_{x \in X} \mid g(x \mid M) - g(x \mid L) \mid dx < \varepsilon_2$.

From the proof of Proposition 2, first we need to show that $\overline{q}_{\{L,H\}}(L)$ is sufficiently small.

$$\overline{q}_{\{L,H\}}(L) - L = \int_{x\in X}\left(\frac{g(x \mid L)f(L)}{g(x \mid L)f(L)+g(x \mid H)f(H)}L + \frac{g(x \mid H)f(H)}{g(x \mid L)f(L)+g(x \mid H)f(H)}H\right)g(x \mid L)dx - L \tag{A1}$$

$$= \int_{x\in X}\frac{g(x \mid H)f(H)g(x \mid L)}{g(x \mid L)f(L)+g(x \mid H)f(H)}(H-L)\,dx \tag{A2}$$

$$\leq \frac{1}{f(L)}\int_{x\in X}\frac{\sqrt{g(x \mid H)f(H)g(x \mid L)f(L)}}{2}(H-L)\,dx \tag{A3}$$

$$= \frac{1}{2}\sqrt{\frac{f(H)}{f(L)}}(H-L)\int_{x\in X}\sqrt{g(x \mid L)g(x \mid H)}dx \tag{A4}$$

$$\leq \frac{1}{2}\sqrt{\frac{f(H)}{f(L)}}(H-L)\sqrt{\int_{x\in X}g(x \mid L)g(x \mid H)dx} \tag{A5}$$

$$< \sqrt{\frac{f(H)}{f(L)}}\frac{(H-L)}{2}\sqrt{\varepsilon_1}, \tag{A6}$$

where (A3) follows from the fact that $ab/(a+b) \leq \sqrt{ab}/2$ for $a, b > 0$, (A5) follows from Schwarz's inequality, and (A6) follows by assumption. Hence $\overline{q}_{\{L,H\}}(L) - L$ can be made arbitrarily small by choice of ε_1.

Next we need to show that $\overline{q}_{\{L,H\}}(M)$ is sufficiently close to $\overline{q}_{\{L,H\}}(L)$.

$$\begin{aligned}\overline{q}_{\{L,H\}}(M) - \overline{q}_{\{L,H\}}(L) &= \int_{x\in X}\left(\frac{g(x \mid L)f(L)}{g(x \mid L)f(L)+g(x \mid H)f(H)}L + \frac{g(x \mid H)f(H)}{g(x \mid L)f(L)+g(x \mid H)f(H)}H\right)\\ &\quad\times\big(g(x \mid M) - g(x \mid L)\big)\,dx\\ &\leq \int_{x\in X}\left(\frac{g(x \mid L)f(L)}{g(x \mid L)f(L)+g(x \mid H)f(H)}L + \frac{g(x \mid H)f(H)}{g(x \mid L)f(L)+g(x \mid H)f(H)}H\right)\\ &\quad\times|g(x \mid M) - g(x \mid L)|dx\\ &\leq H\int_{x\in X}|g(x \mid M) - g(x \mid L)|dx\\ &< H\varepsilon_2.\end{aligned}$$

Hence $\bar{q}_{\{L,H\}}(M) - \bar{q}_{\{L,H\}}(L)$ can be made arbitrarily small by choice of ε_2.

Finally, we need to show that $H - \overline{q}_{\{L,H\}}(H)$ is sufficiently small. Following the same logic as in the first step above,

$$H - \overline{q}_{\{L,H\}}(H) < \sqrt{\frac{f(L)}{f(H)}}\frac{(H-L)}{2}\sqrt{\varepsilon_1},$$

so $H - \overline{q}_{\{L,H\}}(H)$ can be made arbitrarily small by choice of ε_1. *Q.E.D.*

Proof of Proposition 4. Let the Pareto-dominant signalling equilibrium be $(0, s_M, s_H)$. The Pareto-dominant countersignalling equilibrium is that involving the least signalling, or $(0, s_M^*, 0)$, where s_M^* solves $\bar{q}_{\{L,H\}}(L) = M - c(s_M^*, L)$. Since $\bar{q}_{\{L,H\}}(L) > L$, it is clear that Lows are strictly better off. It is less costly to deter Lows from imitating, so it follows that $s_M^* < s_M$ and therefore Mediums are also strictly better off. So if any type is not strictly better off it must be Highs, i.e., $\bar{q}_{\{L,H\}}(H) \leq H - c(s_H, H)$. Since $(0, s_M, s_H)$ is the Pareto-dominant signalling equilibrium, $M - c(s_M, M) = H - c(s_H, M)$. Since $s_M^* < s_M$, $M - c(s_M^*, M) > H - c(s_H, M)$. This implies that beliefs which satisfy the Intuitive Criterion must put probability zero on the event that a signal s in an open neighborhood of s_H was sent by a Medium. Similarly, Lows would never send such a signal. But since $\bar{q}_{\{L,H\}}(H) \leq H - c(s_H, H)$, Highs would have an incentive to deviate from the equilibrium with any signal $s \in N(s_H, \varepsilon)$, where $s < s_H$. Therefore $(0, s_M^*, 0)$ fails the Intuitive Criterion. Finally, receivers are indifferent between any equilibria of the model.

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