*CONSUMPTION-LEISURE TRADEOFFS IN PIGEONS:
EFFECTS OF CHANGING MARGINAL WAGE RATES
BY VARYING AMOUNT OF REINFORCEMENT*

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Pigeons' rates of responding and food reinforcement under simple random-ratio schedules were compared with those obtained under comparable ratio schedules in which free food deliveries were added, but the duration of each food delivery was halved. These ratio-with-free-food schedules were constructed so that, were the pigeon to maintain the same rate of responding as it had under the simple ratio schedule, total food obtained (earned plus free) would remain unchanged. However, any reduction in responding would reduce total food consumption below that under the simple ratio schedule. These "compensated wage decreases" led to decreases in responding and decreases in food consumption, as predicted by an economic model of labor supply. Moreover, the reductions in responding increased as the ratio value increased (i.e., as wage rates decreased). Pigeons, therefore, substituted leisure for consumption. The relationship between these procedures and negative-income-tax programs is noted.

Key words: economics, labor supply, substitution effects, ratio schedules, amount of reinforcement, key peck, pigeons

As early as 1953, B. F. Skinner (1953) noted a direct relationship between operant psychology and economics. He suggested that ratio schedules of reinforcement were directly analogous to piecework wage rates employed in national economic systems. Recently, a number of theoretical and empirical research efforts have exploited this analogy through interpreting behavior under ratio schedules of reinforcement in terms of consumption-leisure choice models as developed in economics to study labor supply (Allison & Boulter, 1982; Battalio, Green, & Kagel, 1981; Battalio & Kagel, 1985; Green, Kagel, & Battalio, 1982; Rachlin & Burkhard, 1978; Staddon, 1979). Under such an approach, the instrumental activity corresponds to a job whose real-wage rate equals the quantity of contingent reinforcers delivered divided by the ratio requirement, and "leisure" (not working) refers to all behavior other than the instrumental response.

A concept that is essential to the economic

model of labor supply concerns an organism's willingness to *reduce* consumption (reinforcement), thus *increasing* leisure (substitute leisure for consumption) as the effort price of consumption increases. Despite the analogies made between economic theories and behavior generated by ratio schedules, there has been little direct or indirect experimental evidence aimed at demonstrating the actual occurrence of these consumption-leisure tradeoffs. The present experiment examines these tradeoffs using procedures quite different from those employed previously, directly controlling for a number of potential artifactual explanations of the substitution effects earlier reported (Battalio et al., 1981; Battalio & Kagel, 1985; Green et al., 1982).

THEORETICAL CONSIDERATIONS/
PREVIOUS PROCEDURES
EMPLOYED TO DEMONSTRATE
SUBSTITUTION EFFECTS

Ratio schedules of reinforcement impose constraints on consumption (reinforcement) in that increases in consumption (increases in reinforcement) can be obtained only through proportionate increases in responding. This constraint can be represented by a straight line, such as OZ, passing through the origin in the

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Fig. 1. (a) Reinforcement feedback function for simple ratio schedule of reinforcement (OZ) with three hypothetical indifference curves. Point A represents most preferred reinforcement-work bundle attainable under schedule constraint OZ. (b) Negative-income-tax procedures. Line OZ is simple RR 50 schedule. OX'X is compound RR + VT free schedule. Under the compound schedule, the subject obtains 50% of its baseline reinforcement rate free under the VT schedule with the remaining reinforcers being earned under the RR component. Economic theory predicts reduced response rate and reinforcement rate (point B) under the compound schedule compared to that on the simple RR schedule (point A).

consumption-response rate space in Figure 1a. The slope of the line OZ is determined by the ratio schedule: the lower the ratio value, the steeper the slope. The subject can perform at any point along the constraint line OZ, with the actual performance representing the most preferred "work-reinforcement bundle" from among the set of available work-reinforcement bundles.

The positively sloped curves of Figure 1a represent indifference curves, each one of which shows a set of work-reinforcement bundles that are assumed to be of equal value to the organism. The positive slope of these curves indicates that the organism would be willing to give up reinforcers provided the loss is matched by a reduction in the response rate. The convexity of the indifference curves indicates, however, that this tradeoff rate (referred to in the economics literature as the

marginal rate of substitution) varies with the size of the reinforcement rate relative to the response rate. That is, proportionately greater reductions in responding are required to compensate for equivalent reductions in reinforcement as one moves toward the origin along any indifference curve.

The extent of the tradeoffs between work and reinforcement (the degree of substitutability of activities) will depend upon the nature of the instrumental-response requirement and the reinforcer employed, as well as on overall economic conditions. For example, if pigeons prefer key pecking to treadle pressing, then, other things being equal, greater substitutability (a flatter slope to the indifference curve) is expected between work and reinforcement with treadle pressing as the instrumental response than is expected with key pecking. Further, in an open-economy setting

(Hursh, 1980), other things being equal, greater substitutability between work and food reinforcement is to be expected than in a closed-economy setting in which there is no outside access to food reinforcement. Finally, the organism is not indifferent between points on *different* indifference curves; it prefers points on the higher curves; that is, packets with more consumption *and* no less responding are always preferred. (This assumes that responding is always a "bad"; extensions of the model to deal with the case where some levels of responding are a "good" can be found in Green et al., 1982; Rachlin & Burkhard, 1978; Staddon, 1979.)

Given the straight-line ratio schedule (line OZ) and the bowed indifference curves, the economic theory of labor supply predicts that the optimal work-reinforcement rate bundle to be chosen by the organism is at the point of tangency between an indifference curve and the ratio constraint line, such as point A in Figure 1a. This is the most preferred consumption-response bundle the organism can attain given constraint OZ, because any other indifference curves intersected by the line would be lower ones. Specifying this equilibrium point is not very informative in its own right, because there appears to be no independent way of determining whether it has been achieved. However, this approach does make specific predictions regarding the direction of changes in the work-consumption bundles chosen by the organism as the schedule constraints are experimentally manipulated.

The fundamental law of labor supply predicts that decreases in the marginal reinforcement rate (MRR)—defined as the change in reinforcement rate resulting from a change in response rate at a point (the slope of the reinforcement feedback function at that point)—within the neighborhood of the original choice point, must result in a decrease in response rate and, consequently, a decrease in consumption. Direct tests of these predicted substitution effects of leisure (not responding) for food were reported in our "negative-income-tax" experiments (Battalio et al., 1981; Green et al., 1982). These experiments involved comparing behavior under simple random-ratio (RR) schedules to behavior under compound schedules involving a RR schedule plus variable-time (VT) free-food deliveries. Under these compound schedules, reinforcers

could be earned according to the ratio schedule in effect. However, in addition, a VT schedule was in effect; it delivered food at variable intervals of time throughout the session, independently of responding. These compound schedules ensured a diminishing MRR by delivering the noncontingent food at 50% of the consumption rate observed under the corresponding simple RR schedule, and by doubling the response requirement for each reinforcer earned under the compound schedule. For example, if the simple RR schedule was an RR 50, and the pigeon obtained two reinforcers per minute on average, then the compound schedule would deliver one noncontingent reinforcer every minute on average under the VT component, while the random-ratio component of the schedule would be set at RR 100.

The procedure and theoretical predictions are illustrated in Figure 1b. Line OZ represents the simple RR schedule, and line OX'X the compound schedule corresponding to this example. Notice that the compound schedule, OX'X, was constructed so that it passed through point A, the preferred work-reinforcement bundle under the original simple RR schedule, OZ, thus ensuring a diminished MRR in the neighborhood of point A. The hypothesized convexity of the indifference curves, in conjunction with the assumption that bundles on higher indifference curves represent more preferred choice points, leads directly to the prediction of less responding and less reinforcement under schedule OX'X as compared to OZ (e.g., from point A to point B in Figure 1b). Parametric variation of these schedules indeed showed that response rates *and* reinforcement rates consistently decreased, as predicted. Further, the size of the substitution effect (reductions in response rate) consistently increased with increases in response requirements, and were quite large, particularly at the higher ratio requirements.

These "negative-income-tax" procedures differ importantly from situations in which delivery of free food is simply added while response requirements and the MRR are held constant (e.g., Allison & Boulter, 1982). Adding free food while holding the response requirement and the MRR constant results in a situation such as line OX'Y in Figure 1b. Such a procedure permits the pigeon to reduce responding (say, from point A to point C) yet

still increase consumption. Consequently, under such a procedure there is no need to trade off consumption against leisure (not responding). Under the negative-income-tax procedures, however (line OX'X in Figure 1b), the pigeon can reduce responding only by reducing consumption also. The negative-tax procedures thus provide a strict test of the theory because the predicted reduction in responding and consumption is based directly on the convexity of the indifference curves, which in turn is based on the presumed substitutability of consumption for leisure.

Unfortunately, the "negative-income-tax" procedures can be criticized on the grounds that the delays to reinforcement were greater under the compound schedule than under the simple schedule of reinforcement (i.e., delay to reinforcement was greater under RR 100 than under RR 50). Given the effect that delay of reinforcement has on behavior, this increase in delay can account completely for the reductions in consumption and responding observed. The present experiment controls for this potential artifact through a modification of the "negative-income-tax" procedures so that reductions in the MRR under the compound schedule result from changing the amount of food delivered per reinforcement while holding response requirements constant. The compound RR + VT schedules continued to deliver 50% of baseline consumption on a noncontingent basis. However, the amount of food delivered per reinforcement was halved under the RR component of the schedule while the RR requirement remained fixed at the value employed under the simple ratio schedule used in establishing the baseline consumption-response rate. For example, if under the simple baseline RR 50 schedule each reinforcement was 4 s of food and the pigeon obtained one reinforcement per minute on average, then the compound schedule would deliver 2 s of food per minute, noncontingently under the VT component of the schedule; and the RR requirement would remain fixed at 50, but earned reinforcers would now also consist of 2-s access to food per reinforcement. In terms of Figure 1b nothing has changed. However, inasmuch as response requirements on the RR component of the compound schedule equal those of the baseline schedule, any variation in costs of responding

resulting from changing response requirements is eliminated.

METHOD

Subjects

Four experienced, male, White Carneaux pigeons were maintained at between 80% and 80% + 20 g of their free-feeding body weights throughout the experiment. Water and grit were always available in their home cages. All 4 pigeons had participated in our earlier "negative-income-tax" experiments.

Apparatus

The experiment was conducted in a sound-insulated pigeon test chamber that measured 30 cm long by 24 cm wide by 29 cm high. The response key, 2.5 cm in diameter, was made of clear acrylic plastic. Its center was located 19 cm above the floor and 12 cm from each side of the test chamber. The key was transilluminated with amber light and required a force of at least 0.15 N to operate. Effective key pecks produced an auditory feedback click by operating a 28-V relay. Reinforcement consisted of a timed period of access to mixed grains during which time the food hopper (located below the response key and 3 cm from the floor) was elevated and lit by a 7-W white bulb. A photocell was mounted in the food hopper so that when the pigeon put its head into the hopper, it broke the photocell beam. Reinforcement periods were timed from when the animal broke the photocell beam, and lasted for either 2 or 4 s. General chamber illumination was provided by a 7-W houselight situated above the response key, with the light deflected upward. Both the houselight and response key were darkened during food delivery. A fan provided ventilation and masked extraneous sounds. All scheduling and recording were performed automatically by solid-state programming equipment located in an adjacent room.

Procedure

The effects of two classes of experimental conditions were studied in the present experiment: (1) Simple random-ratio schedules of reinforcement (RR): Under these schedules, food delivery was dependent upon the animal's completing a required number of key-

peck responses, the actual number of responses necessary for each reinforcement varying irregularly and unpredictably from reinforcement to reinforcement. Random-ratio schedules studied were RR 25, 50, 85, 100, 200, and 400. Baseline conditions consisted of simple RR schedules with 4-s access to the food hopper per reinforcement, while other simple RR schedules involved 2-s access to the food hopper per reinforcement. (2) The second class of conditions was random-ratio schedules (RR) plus variable-time (VT) free-food deliveries (RR + VT free): Under these conditions, reinforcement was still dependent upon the animal's emission of key pecks according to the ratio schedule in effect, as before. However, in addition, a VT schedule was in effect that delivered food at variable intervals of time throughout the session, completely independently of responding. The rate at which the noncontingent food was delivered was equal to the mean reinforcement rate from the last five sessions of the corresponding baseline RR schedule, but reinforcement magnitude now consisted of 2-s access to the food hopper. In addition, all earned reinforcers also consisted of 2-s access to the food hopper. VT deliveries were programmed according to the schedule suggested by Fleshler and Hoffman (1962). The RR requirement in effect was the same as that employed in the corresponding baseline period. Consequently, if the bird responded at the same rate during the RR + VT free schedule as during the corresponding baseline period, then it would obtain the same total amount of food—only more frequently and in smaller amounts per delivery. However, half the food would be presented freely throughout the session whereas the other half was dependent on responding. Reduced responding during this condition would result in a decrease in the rate of contingent reinforcement but would have no effect on the number or rate of delivery of the free food. The RR + VT schedules were conducted under RR values of 25, 50, 85, 100, 200, and 400.

Conditions with RR + VT free schedules were designed to test the convexity of the indifference curves as indicated in Figure 1b. In each case, these schedules immediately followed a baseline RR schedule. For example, Bird 29 in Condition 1 was studied on an RR

50 schedule with 4-s reinforcement and obtained an average of 75.8 reinforcers, or a total consumption time of 303.2 s of access to the food hopper. In Condition 2, the number of free-food deliveries was set at 76.0, but access time per reinforcement was now 2 s, for a total consumption time of 152 s at the food hopper, 50% of the baseline rate. Earned reinforcers now also consisted of 2-s access to the food hopper, and the RR requirement remained constant. Consequently, if the bird responded at its previous baseline rate, total food consumption would be unaffected; if the response rate dropped to zero, total food consumption time would be halved.

Each condition was maintained until the following criteria for stability were attained: (a) The bird had been on the condition for at least 21 days; (b) the last 9 days were divided into three successive blocks of three sessions each, and the medians of these blocks (Md_i) showed neither an upward nor a downward trend—that is, neither $Md_1 < Md_2 < Md_3$ nor $Md_1 > Md_2 > Md_3$; and (c) there was no apparent trend during the final 5 days of the condition. Table 1 presents the order in which the experimental conditions were studied and the number of sessions on each.

Sessions were conducted 7 days per week, with each session lasting 40 min, excluding the time during which the food hopper was presented. Thus the session-control clock was stopped for the reinforcement period plus whatever latency period was involved in the birds' responding to the food-hopper presentations.

RESULTS

The results are summarized in Table 1, which presents for each pigeon the number of free-food deliveries, the mean response rate, the mean number of total food deliveries (contingent plus noncontingent) obtained, and mean total consumption time over the last 5 days of each condition.

RR + VT free schedules were implemented in 16 different periods across the 4 subjects. As already noted, these conditions immediately followed their respective baseline RR schedule and were designed to test the convexity of the indifference curves (recall Figure 1b). In all 16 cases, response rates and

Table 1

Summary of results for each pigeon, including number of sessions in each condition, ratio requirement, seconds of access to food per presentation (sec food), number of free-food deliveries, mean response rate, total food deliveries (contingent plus free food), and total consumption time. Results are means over the last five sessions of each condition.

Condition	Number of sessions	RR requirement	Sec food	No. free-food deliveries	Resp. rate (resp./min)	Total food deliveries	Total consumption time (sec)
Bird 29							
1	35	50	4	0	95.4	75.8	303.2
2	28	50	2	76	48.2	114.8	229.6
3	32	50	2	0	97.7	78.7	157.4
4	21	100	4	0	113.1	45.2	180.8
5	21	100	2	45	15.5	51.3	102.8
6	30	100	2	0	88.0	35.1	70.4
7	39	200	4	0	75.9	15.9	63.6
8	24	200	2	16	2.6	16.2	32.4
9	21	200	2	0	56.2	11.0	22.0
10	22	400	4	0	32.6	3.2	12.8
11	22	400	2	0	4.4	0.4	0.8
12	23	25	4	0	81.0	130.1	520.4
13	24	25	2	129	31.9	184.1	368.4
14	21	25	2	0	91.3	146.1	292.4
15	23	50	4	0	58.6	45.7	182.8
16	22	100	4	0	59.6	22.9	91.6
17	29	50	4	0	66.2	53.0	212.0
Bird 30							
1	31	50	4	0	173.7	139.6	558.4
2	21	50	2	140	121.4	237.5	475.2
3	24	50	2	0	162.9	130.2	260.4
4	27	100	4	0	164.6	65.6	262.4
5	41	100	2	66	90.2	102.9	206.0
6	22	100	2	0	186.4	75.0	150.0
7	63	200	4	0	127.5	24.7	98.8
8	46	200	2	25	72.6	40.3	80.8
9	23	200	2	0	146.6	29.3	58.8
10	21	400	4	0	121.8	12.0	48.0
11	24	400	2	12	50.3	16.8	33.6
12	36	400	2	0	79.0	7.8	15.6
13	21	25	2	0	173.2	292.5	585.2
14	21	50	4	0	179.8	143.8	575.2
Bird 47							
1	23	50	4	0	112.7	89.1	356.4
2	23	50	2	89	39.8	120.5	241.2
3	22	50	2	0	119.8	96.1	192.4
4	58	85	4	0	92.8	43.5	174.0
5	21	85	2	43	36.4	60.4	120.8
6	26	85	2	0	109.5	51.0	102.0
7	26	200	4	0	87.8	17.3	69.2
8	26	200	2	17	15.6	20.8	41.6
9	25	200	2	0	89.0	17.4	34.8
10	30	400	4	0	82.7	8.6	34.4
11	28	400	2	0	65.8	6.6	13.2
12	22	25	4	0	91.0	145.3	581.2
13	23	25	2	145	30.8	197.2	394.4
14	23	25	2	0	98.8	157.6	315.2
15	25	50	4	0	93.4	75.7	302.8
Bird 49							
1	22	50	4	0	143.6	115.3	461.2
2	22	50	2	115	29.3	137.3	274.8

Table 1 (Continued)

Condition	Number of sessions	RR requirement	Sec food	No. free-food deliveries	Resp. rate (resp./min)	Total food deliveries	Total consumption time (sec)
3	26	50	2	0	155.4	124.3	248.8
4	21	200	4	0	143.9	29.3	117.2
5	22	200	2	29	11.6	31.4	62.8
6	21	200	2	0	137.5	27.4	54.8
7	23	100	4	0	148.9	59.6	238.4
8	21	100	2	59	24.9	69.5	139.2
9	21	100	2	0	153.6	61.4	122.8
10	27	400	4	0	134.2	13.2	52.8
11	29	400	2	0	124.0	12.4	24.8
12	22	25	4	0	132.0	212.3	849.2
13	22	25	2	212	32.6	272.2	544.4
14	21	25	2	0	144.3	228.1	456.4
15	21	50	4	0	148.1	118.5	474.0

reinforcement rates decreased relative to the respective baseline RR condition, as predicted. In no case was the reduction in response rate less than 30% of the corresponding baseline period, which corresponds to a 15% reduction in the consumption rate relative to baseline. For example, Bird 29 showed a 49% reduction in response rate, from 95.4 responses per minute under the baseline RR 50 schedule to 48.2 responses per minute under the RR 50 + VT free condition, resulting in a 24% reduction in total consumption time from 303.2 to 229.6 s of food, with approximately two thirds of the food deliveries being unearned (see Table 1). Food-deprived birds thus gave up food in spending more time in nonwork (leisure) activities.

Table 2 presents the percentage reductions in response rates under each RR + VT free schedule as compared to response rate under the corresponding simple baseline RR schedule. For all subjects, the size of the substitution effect (percentage decrease in responding when changed from baseline RR schedule to RR + VT free schedule) generally increased (in absolute value) with increases in the ratio requirement. Pearson correlation coefficients relating the ratio requirement to the size of the substitution effect also are reported in Table 2 for each subject. In parentheses are the probabilities of these coefficients under the null hypothesis of a zero correlation between ratio size and substitution effect. Although the power of any individual subject test is obviously weak, given the paucity of observations, the four independent tests can be com-

bined; using Pearson's p_λ test (Maddala, 1977, pp. 47-48), the null hypothesis that all the correlations are zero can be soundly rejected [χ^2 (8, $N = 4$) = 21.6, $p < .001$]. A similar increase in the absolute size of the substitution effect with increases in the ratio requirement was reported in our earlier experiment in which the RR + VT free schedule varied the RR requirement relative to baseline while holding reinforcement magnitude constant (Green et al., 1982).

Table 3 isolates the effect on behavior of the free-food deliveries. The number of earned reinforcements under the RR + VT free schedule is compared with the number earned

Table 2

Substitution effects (percentage decrease in responding) as a function of ratio requirement.

RR requirement	Percentage decrease in response rate ^a			
	Bird 29	Bird 30	Bird 47	Bird 49
25	61	—	66	75
50	49	30	65	80
100 ^b	86	45	61	83
200	97	43	82	92
400	—	59	—	—
Correlation coefficient	.88	.91	.85	.99
(Probability $\neq$ 0)	(.12)	(.09)	(.15)	(.01)

^a Percentage decrease in responding under RR + VT free schedule relative to response rate under corresponding baseline simple RR schedules.

^b For Subject 47, values are for RR 85.

Table 3

Effect of free food on earned and total reinforcement. In all conditions, duration of access to food was 2 s.

Schedule	Bird 29 Number of food deliveries			Bird 30 Number of food deliveries			Bird 47 Number of food deliveries			Bird 49 Number of food deliveries		
	Free	Earned	Total	Free	Earned	Total	Free	Earned	Total	Free	Earned	Total
RR25	0	146.1	146.1	—	—	—	0	157.6	157.6	0	228.1	228.1
RR25 + free	129.0	55.1	184.1	—	—	—	147.4	49.8	197.2	214.6	57.6	272.2
RR50	0	78.7	78.7	0	130.2	130.2	0	96.1	96.1	0	124.3	124.3
RR50 + free	76.2	38.6	114.8	140.2	97.5	237.7	89.0	31.5	120.5	114.4	22.9	137.3
RR100 ^a	0	35.1	35.1	0	75.0	75.0	0	51.0	51.0	0	61.4	61.4
RR100 + free	45.4	5.9	51.3	66.8	36.1	102.9	43.4	17.0	60.4	59.6	9.9	69.5
RR200	0	11.0	11.0	0	29.3	29.3	0	17.4	17.4	0	27.4	27.4
RR200 + free	16	0.02	16.0	24.4	15.9	40.3	17.4	3.4	20.8	29.0	2.4	31.4
RR400	—	—	—	0	7.8	7.8	—	—	—	—	—	—
RR400 + free	—	—	—	11.6	5.2	16.8	—	—	—	—	—	—

^a For Bird 47, these values are for RR 85.

under the corresponding simple RR schedule with the same RR requirement *and* the same reinforcement magnitude (2-s access to food; e.g., Conditions 3 and 2, Conditions 9 and 8, etc., of Table 1). In all cases, the free food by itself reduced the number of earned reinforcers (hence the response rate) but increased total food obtained (earned plus free), results similar to those reported by Allison and Boulter (1982). However, unlike the “negative-income-tax” results reported in Table 2, here the constraints permitted the birds to both *increase* the total food reinforcement rates and simultaneously *reduce* their response rates (as depicted in Figure 1b by point C on line OX’Y), and indeed they did so in virtually all cases. For example, Bird 29 under the simple RR 25 schedule obtained 146 food deliveries, whereas under the RR 25 + VT free schedule it obtained a total of 184 reinforcers of which only 55 were earned; total responding (and earned reinforcers) was 62% lower while total food reinforcement increased by 26%. Recalling Figure 1b, reducing responding while simultaneously increasing food reinforcement is not technically possible under the “negative-income-tax” procedures.

Also note in Table 3 that as the RR requirement increased, the number of free food deliveries decreased. However, none of the birds reacted to this by reducing its responses (and the corresponding number of earned reinforcers) an equivalent amount. Rather, each tended to reduce responding and earned reinforcers by a proportionately greater

amount. For example, Bird 29 received 129 free food deliveries under the RR 25 + VT free condition compared to 45.4 free under the RR 100 + VT free condition, or 65% fewer free deliveries. Nevertheless, earned reinforcers dropped from 146.1 under the simple RR 25 schedule to 55.1 under the RR 25 + free condition, a reduction of 62%, whereas earned reinforcement decreased from 35.1 under the simple RR 100 schedule to 5.9 under the RR 100 + free condition, a reduction of 83% in earned reinforcers. The magnitude of the impact of a given number of free reinforcers depends at least in part, then, on the ratio requirement in effect. This, too, matches our earlier findings as well as those of Allison and Boulter (1982).

Figure 2 shows the relationship between response rate and the real-wage rate—seconds of food per reinforcement divided by the RR requirement—for each subject. (For ease of exposition and analysis, we have multiplied this ratio by 100 throughout.) Filled circles show periods with 2 s of access per reinforcement, and Xs indicate periods with 4 s of food per reinforcement. This figure permits us to evaluate two issues of interest: First, what happens to the response rate as the real-wage rate varies; second, are there systematic deviations in response rates between the two reinforcement magnitudes when the real-wage rate is equivalent?

With respect to changes in response rates as real-wage rates varied, all birds displayed a modestly bitonic response pattern: As the

Fig. 2. Response rates (responses/min) under different real-wage rates. Real-wage rate = (seconds of food per reinforcement/RR schedule) $\times$ 100. Real-wage rates and their corresponding RR values are: 0.5, RR 400; 1.0, RR 400 & RR 200; 2.0, RR 200 & RR 100; 4.0, RR 100 & RR 50; 8.0, RR 50 & RR 25; 16.0, RR 25. Filled circles represent conditions with 2-s food reinforcement, Xs with 4-s food. Smooth curves were obtained by fitting second degree polynomial to the data by the method of least squares.

reinforcement schedule became richer, the response rate increased at first, reached a maximum value, and then declined moderately in 3 of the 4 subjects. Comparing response rates with 2-s (filled circles) and 4-s (Xs) of reinforcement, holding real-wage rates constant, all birds responded at a higher rate with 2-s than with 4-s food at wage-rate values of 1 and 2. At the higher wage rates, there were no systematic differences in response rates between the two reinforcement magnitudes.

DISCUSSION

This experiment addressed substitutability of leisure for consumption, employing a procedure in which reductions in the marginal reinforcement rate were accompanied by a constant response requirement per reinforcement. By holding the response requirement constant, any independent effects of changing response requirements on response rates—or,

more generally, the cost of responding—were eliminated. Consistent with predictions from economic theory, hungry pigeons maintained at 80% of normal body weight consistently reduced consumption and response rates, often by large amounts, as a consequence of the reduced marginal reinforcement rates of the RR + VT free schedules. Moreover, the size of these substitution effects (reductions in the response rate) increased with increases in the response requirement, providing a systematic replication of the results obtained in the earlier open-economy experiments that employed different experimental procedures (Battalio et al., 1981; Green et al., 1982).

As the ratio requirements were varied, response rate showed moderately bitonic response functions. That is, as the ratio requirement was reduced, rate of responding increased, up to a point, after which additional reductions in the ratio requirement led to modest decreases in rate of responding (see

Figure 2). More dramatic bitonic response functions were reported in our earlier experiments (Battalio et al., 1981; Green et al., 1982) in the sense of a sharper reduction in responding at higher real-wage rates. One explanation for this difference is that higher real-wage rates were studied in these earlier experiments (3 s of food under an RR 12.5 was the highest reinforcement rate in the earlier work as compared to 4 s of food under an RR 25 here). Conditions here, and in the earlier experiments, strictly satisfy the stringent requirements for observing monotonically increasing response rates throughout, as predicted by the matching law (Kagel, Battalio, & Green, 1983; Lea, 1978; Prelec, 1982). Therefore, these results are in closer accord with the economic model than with matching.

The economic model appears to account for the present results more readily than would a traditional reinforcement account. A reinforcement account would predict a decrease in responding due to the addition of the free food on the VT schedule. This would likely result from the free delivery of food reinforcing either nonresponding or longer interresponse times (although a VT schedule will not always reduce response rate; e.g., see Burgess & Wearden, 1986; Lattal, 1973), or through degradation of contingency (Hammond, 1980). However, a reinforcement account would appear to remain silent regarding the effect observed here of the VT schedule on overall food consumption. Under the "negative-income-tax" procedure, any reduction in responding relative to the baseline schedule led to a decrease in the food-consumption rate as well. Although it is not clear that a reinforcement model can handle this result, the economic model, as shown, predicts the reduction in both responding and reinforcement. It is also not obvious that a reinforcement account would predict greater reductions in responding at the higher RR values inasmuch as the absolute number of free foods delivered was considerably fewer than at lower RR values (see Table 3). This is one of the more striking aspects of our results. Further, at equivalent RR values but with free food added (e.g., RR 25 compared to RR 25 + free), a reduction in responding would be expected. But here again a reinforcement account remains silent with regard to whether the total amount of food

obtained would increase, decrease, or remain constant. However, the economic model predicts that under this condition, the organism will increase its total food consumption (see Table 3, and Allison & Boulter, 1982; recall Figure 1b, line OX'Y).

In addition, a reinforcement account might be expected to predict a reduction in responding whenever reinforcement magnitude decreased from 4 s to 2 s (this is essentially the prediction of the matching law). However, if response rates under comparable simple RR schedules providing 2-s versus 4-s food reinforcement are compared (e.g., Conditions 1 and 3, 4 and 6, etc.; see Table 1), then higher rates of responding occurred with 2-s than with 4-s food in 11 of 19 comparisons. The economic model relates these reductions in response rate to being on the descending (high real-wage rate) limb of the bitonic response curves of Figure 2, where reductions in the real-wage rate *should* result in modest increases in response rates. The data support this prediction as increases in response rate under 2 s versus 4 s of reinforcement were indeed concentrated at these higher real-wage rates (lower RR requirements): Under the RR 25, 3 of 3 subjects increased responding, whereas under the RR 400, 4 of 4 subjects reduced responding under 2-s as compared to 4-s food reinforcement. Finally, irrespective of whether responding increased or decreased as a result of a decrease in the amount of food reinforcement, both responding and consumption decreased under the "negative-income-tax" procedures, as the economic model predicts. Thus, reductions in responding under these procedures cannot be attributed solely to the decrease in reinforcer magnitude from 4 s to 2 s.

At equivalent real-wage rates, there were consistent differences in response rates with 2 s as compared to 4 s of food reinforcement only at the higher ratio requirements (lower real-wage rates). The size of these differences was small, however, and there were no systematic differences at the higher real-wage rates (where the ratio requirements are lower; see Figure 2). The latter is important because it indicates that exact compensation was achieved, or close to being achieved, at all ratio requirements: In terms of Figure 1b, the compound schedule, OX'X, passed through

(or close to) the point chosen under the simple baseline RR schedule (point A on line OZ in Figure 1b) in terms of effective value.

The analogy between a negative-income-tax program and the procedures employed here is based on the fact that a negative-income-tax program (or most welfare schemes, for that matter) involves delivery of nonwage income (the VT free component of the compound schedules) in conjunction with a reduction in the MRR associated with earned income inasmuch as any increase in earned income is accompanied by a reduction in benefits, typically at very high marginal tax rates in terms of benefits lost. As shown here and elsewhere, given the substitutability of consumption for leisure, any such welfare scheme introduces incentives to reduce the amount of labor supplied.

In this context Timberlake (1984) argued that given the tendency of both pigeons and people to value future rewards less than current rewards, the adverse incentive effects of such welfare schemes can be minimized as follows:

Any welfare procedure providing a large segment of guaranteed income just before or during work opportunities should produce less work than income following work that compensates for any unearned amount. Thus, minimum welfare "payments" are likely to occur when an opportunity to work for immediate income is provided prior to receiving any subsequent guaranteed income. (p. 123)

Given a tendency to value future rewards less than current payoffs, we are in complete agreement with Timberlake's argument regarding incentives. However, it is important to recognize that under such conditions any delays in delivery of guaranteed income constitute a reduced real level of guaranteed income, at least as far as the recipients of such income are concerned. Therefore, potential welfare recipients would be worse off, because a delay in delivery of guaranteed income is equivalent in value to a reduction in the level of guaranteed income. This tends to reduce the disincentive effects but is not without cost from the recipient's point of view. (Another factor to be noted is that the disincentive effects may be attenuated by the level of need to which the recipients are consigned in our

society [Green & Green, 1982].) A significantly more challenging task, as we see it, is to devise income transfer schemes for the needy that minimize work disincentive effects without reducing the value of welfare payments. Finally, to the extent that some disincentive effects are unavoidable, we must accept them as necessary costs of achieving a desired improvement in individual and societal welfare, and we must decide what to do based on the incremental costs and benefits involved.

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