*THE EFFECTS OF COMPONENT DURATION ON
MULTIPLE-SCHEDULE PERFORMANCE IN
CLOSED AND OPEN ECONOMIES*

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Pigeons responded on multiple variable-interval variable-interval schedules of reinforcement in an open and a closed economy. Equal duration components were increased in duration while the component rates of reinforcement were held constant, the component schedules were reversed, and component duration was decreased. In the open economy, daily sessions were limited to 1 hr, and subjects were maintained at 80% of their free-feeding weights through supplemental feeding when necessary in their home cages. In the closed economy, subjects were housed in their experimental chambers and no deprivation regimen was enforced. Relative response rate decreased as components were lengthened in the open economy, whereas in the closed economy relative rate increased as components were lengthened. Response proportions overmatched reinforcer proportions to a greater extent at long component durations in the closed economy, but there was no systematic effect of component duration on responding in the open economy.

Key words: multiple schedules, component duration, closed economy, variable-interval schedules, overmatching, key peck, pigeons

In multiple schedules, two or more independent schedules of reinforcement, each correlated with a different stimulus, are alternated at some specified interval. The alternation of schedules, or components, typically occurs independent of behavior. The distribution of responses between the successive components of a multiple variable-interval schedule is well described by a power function that relates the number of responses emitted per component and the number of reinforcers obtained per component. This function, called the generalized matching law (Baum, 1974b), takes the form:

$$(P1/P2) = a(R1/R2)^b, \quad (1)$$

in which P represents the rate of responding emitted within a component, R represents the obtained rate of reinforcement within a component, and the subscripts denote the components of a multiple schedule. The fitted parameter a represents a constant preference for one of the alternatives that cannot be accounted for by the obtained distribution of reinforcers

(bias), and the fitted exponent b represents a metric by which changes in behavior produced by a given change in reinforcement can be measured, and is said to capture the degree to which matching takes place on multiple schedules. Perfect matching is the case in which b is equal to 1.0, whereas values of b less than or greater than 1.0 represent instances in which undermatching or overmatching has been obtained. The absence of bias is indicated by values of a equal to 1.0. McSweeney, Farmer, Dougan, and Whipple (1986), in a selective review of multiple-schedule literature, found that the median obtained value of b was .46, and the median value of the bias parameter was 1.0 across studies. McSweeney et al. limited their analysis to multiple schedules that used interval schedules as the component schedules of reinforcement. Their results suggest that multiple variable-interval schedule performance can be characterized as one of undermatching with no bias.

Although most of the research conducted with multiple schedules has focused on the relation between response allocation and the rate of scheduled (and unscheduled) rewards within components, variables other than rate of reinforcement have been shown to have systematic effects on multiple-schedule performance. Undermatching is the typical result, but does not necessarily occur if schedules with

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short (5 to 10 s) component durations are employed (de Villiers, 1977; Killeen, 1972; Menlove, 1975; Merigan, Miller, & Gollub, 1975; Shimp & Wheatley, 1971; Spealman, 1976; Todorov, 1972; Williams, 1980), deprivation is minimal (Charman & Davison, 1983; Herrnstein & Loveland, 1974), or long (24-hr) session durations are employed (Elliffe & Davison, 1985).

Component duration is the variable that has received the most attention, but its effects are unclear. Results from some studies suggest that the effects of component duration are peculiar to those instances in which the component schedules are held constant across conditions, because the effect is eliminated when schedules are reversed between components (Charman & Davison, 1982). Other results suggest that interactions between components are enhanced by short-component multiple schedules and decrease as component durations are increased (Ettinger & Staddon, 1982; Silberberg & Schrot, 1974; Williams, 1983). The main evidence in favor of the short component effect is from a study conducted by Shimp and Wheatley (1971). They were the first to demonstrate that changes in component duration alone were sufficient to change the behavior maintained by multiple schedules in such a way that the relative response rate as calculated for the richer component increased as equal component durations were decreased. At a component duration of 10 s relative response rate approximately equaled relative reinforcement rate, and reanalysis of their data yields estimates of b that increased from .41 at component durations of 180 s to .95 at component durations of 10 s. Todorov (1972) replicated the main findings of Shimp and Wheatley. Edmon (1978), in a reanalysis of the data from these two studies, showed that the changes in relative rate of responding were due primarily to changes in absolute response rate during the component with the richer rate of reinforcement. Response rate in the poorer component, according to Edmon, remained relatively invariant.

The evidence for the effects of deprivation level on multiple-schedule performance comes from studies in which pigeons' body weights were varied systematically from 80% to 100% of free-feeding weights (Charman & Davison, 1983; Herrnstein & Loveland, 1974). Across a range of component rates of reinforcement,

the relative rate of responding for the component with more frequent reinforcement increased as body weight approached free-feeding levels. Although absolute rates of responding were suppressed in both the poorer and richer components as a function of increasing body weight, matching was obtained at 100% of free-feeding weights. At 80% of free-feeding weights, subjects undermatched with respect to the obtained rates of reinforcement.

Session duration is another factor that has been shown to affect the undermatching relation typically found on multiple schedules of reinforcement. Elliffe and Davison (1985) examined the responding of two pigeons on multiple variable-interval variable-interval schedules (*mult VI VI*) with 23.5-hr sessions and a fixed component duration of 150 s. Subjects could respond on the multiple schedule at any time during the course of a session, and all food was obtained from the multiple schedules. Over a range of reinforcement ratios both subjects exhibited overmatching; the mean estimate of b was approximately 1.5. Because the *mult VI VI* schedules were available continuously, and no deprivation regimen was employed, the subjects, presumably, operated under conditions of minimal deprivation. This, however, does not account for the overmatching obtained in this study, because pigeons in short sessions tend to match, but not overmatch, as deprivation is decreased (Herrnstein & Loveland, 1974). The controlling variable for this overmatching, then, seems to be the use of long session durations.

There is an alternative explanation for the results obtained by Elliffe and Davison (1985) that stems from the only published study in which component duration was manipulated while body weight was allowed to exceed 80% of free-feeding weight, and in which the multiple schedule was continuously available. Norborg, Osborne, and Fantino (1983) examined response rates with multiple fixed-ratio fixed-ratio schedules (*mult FR FR*) as a function of component duration and session length. In their Experiment 3 at session durations of 23.5 hr subjects were housed in their experimental chambers and no explicit deprivation regimen was used. As such, body weight was free to vary and was strictly determined by contact with the experimental contingencies. Norborg et al. found that as component

duration was increased from 30 s to 705 min, response rate in the component with the richer rate of reinforcement remained invariant whereas absolute rate in the leaner component was a decreasing function of component duration; consequently the relative rate of responding for the smaller FR schedule increased as component duration was lengthened. These findings are completely opposite to the findings from studies in which shorter session durations were used and component duration or deprivation was systematically varied. One explanation for the results of Norborg et al. is that because a *mult* FR FR schedule is not functionally equivalent to a *mult* VI VI schedule, the effects of component duration on responding will be different. An alternative explanation is that the effects of component duration are different due to the use of long session durations. This latter explanation suggests that the overmatching obtained by Elliffe and Davison may have been due to an interaction between the component duration used in their study and session length. If relative rate of responding on a *mult* VI VI schedule with long sessions increases as a function of lengthening component duration, as it does on a *mult* FR FR schedule, overmatching could result.

Recent theoretical accounts provide yet another explanation for the results of Norborg et al. (1983) and Elliffe and Davison (1985). Lea (1978) and Hursh (1980) have proposed that operant procedures can be conceptualized as economic systems. According to Hursh's view, any time total daily intake of a commodity, such as food, is independent of a particular class of operant, such as key pecking, an open economy is in effect. The situation in which a subject receives food reinforcers during an experimental session and is also provided with postsessional food constitutes an open economy (e.g., Herrnstein & Loveland, 1974; Shimp & Wheatley, 1971). At the other extreme, when total daily intake is strictly dependent on contact with the experimental contingencies, a closed economy is said to be in effect. Hursh suggests that given identical experimental designs that differ only in terms of the economic context used, the behavior one observes will most likely reflect this difference. Collier, Hirsch, and Hamlin (1972), for example, studied two rats that lived in their experimental chambers continuously and re-

ceived no supplemental food. Both rats showed strongly increasing response rates at the same FR value that commonly produced behavioral strain in the more typical short session plus postsessional feeding procedure. Thus, the results obtained by Norborg et al. and Elliffe and Davison may not have been due to session length but to the absence of postsessional feeding (closed economy) engendered by their respective procedures.

The main question addressed by the present experiment is whether the differences in results between Norborg et al. (1983) and others were due to the use of *mult* FR FR schedules (as opposed to *mult* VI VI) or to the use of a closed (as opposed to an open) economy. To this end, the effects of component duration on responding in a *mult* VI VI schedule were examined under a closed economy with long (23.5 hr) sessions and an open economy with short (1 hr) sessions. Comparisons of performance under open and closed economies usually have been done between subjects and, sometimes, between experiments. In the present experiment, the same subjects were exposed to both types of economies. To facilitate comparison with previous studies that have examined the effects of component duration on responding, body weights for subjects in the open economy were maintained at 80% of free-feeding weights; for subjects in the closed economy, no deprivation regimen was used. The results should also permit us to assess whether the results of Elliffe and Davison (1985) were influenced by component duration.

METHOD

Subjects

Four male pigeons served as subjects. Birds G46, R39, and 886 were White Carneaux and had previous exposure to multiple schedules. Bird Y2 was an Indian Mondain and had been trained on concurrent schedules. All subjects were examined under open and closed economies in all conditions. Water and grit were freely available in home cages regardless of economic context and were also available in experimental chambers when a closed economy was in effect. All subjects started a condition at 80% of their free-feeding weights regardless of economic context but were only maintained at these weights during the open economy segments of the experiment. This was

Table 1

Sequence of experimental conditions for each subject, component durations in seconds, VI schedule values in seconds, and economic context. All subjects were placed on a deprivation regimen following closed-economy conditions.

Condition	Component duration	VI schedules		Economy	
		Red	Green	R39 & Y2	G46 & 886
1	10	30	90	Open	Closed
2	10	30	90	Closed	Open
3	30	30	90	Open	Closed
4	30	30	90	Closed	Open
5	90	30	90	Open	Closed
6	90	30	90	Closed	Open
7	180	30	90	Open	Closed
8	180	30	90	Closed	Open
9	300	30	90	Open	Closed
10	300	30	90	Closed	Open
11	180	90	30	Open	Closed
12	180	90	30	Closed	Open
13	10	90	30	Open	Closed
14	10	90	30	Closed	Open

done through supplemental feeding, when necessary, after an experimental session.

Apparatus

A standard operant chamber with internal dimensions of 30.5 by 30.5 by 40.5 cm was enclosed in a larger wooden box. The wooden box was ventilated at all times by an exhaust fan rated at 45 cfm (0.47 L/s). The top and sides of the chamber were constructed of clear Plexiglas. A 1-W miniature bulb located in the ceiling near the rear wall provided general chamber illumination. A mounting bar for removable water and grit cups was located 7 cm above a grid floor. The tops of the cups (when present in the chamber) were no greater than 10 cm above the chamber floor. Two pigeon keys, 2.5 cm in diameter and requiring a force of approximately 0.1 N for operation, were mounted on an aluminum front wall. Each key was mounted 25 cm above the floor and 5 cm from the midline plane of the front panel. Red and green stimuli were projected on the left key from behind by a 28-V IEE in-line projector. The other key remained unlit and inoperative in all conditions. The hopper opening (illuminated with white light when food was available) was centrally located 10 cm above the floor. The reinforcer was 3.5-s access to grain. During reinforcement both the

keylight and houselight were darkened. All experimental events were controlled, and data collected by, conventional electromechanical equipment situated in an adjacent room.

Procedure

Throughout all conditions subjects' responses were reinforced according to a two-component *mult* VI VI schedule of reinforcement. Component stimuli were red and green keylights that alternated in strict succession on the left key. Component durations were equal and varied over conditions. Table 1 shows the component durations investigated. In Conditions 1 through 10 component durations were presented in an ascending order, and responses in the presence of red were reinforced according to a VI 30-s schedule. Responses in the presence of green were reinforced according to a VI 90-s schedule. Interreinforcement intervals were based on an arithmetic scale. In Conditions 11 through 14 the schedules were reversed and component durations were presented in a descending order.

Reinforcers set up in a component but not obtained by the end of that component were held over until the next presentation of that component. Feeder operation did not reduce the time in which a subject could respond in a component. Each session was terminated after an equal number of both components had been presented. Total duration of exposure to both components was either 1 hr (open economy) or 23.5 hr (closed economy). For each bird, sessions were continued in a condition until a stability criterion had been met: The means of relative response rate from three consecutive blocks of three sessions could deviate from each other by no more than .05 and no upward or downward trends were apparent. Assessment of stability began after the seventh session of a condition. Responses made and the number of reinforcers obtained in each component were recorded separately.

The closed economy differed from the open economy in that subjects lived in their experimental chambers, the houselight was switched off at 5:45 p.m. and on at 5:45 a.m. each day, body weight was under the subject's control, grit and water were freely available in the experimental chambers, and all food was obtained through contact with the programmed contingencies of reinforcement. Each day at

noon the subjects were removed from their chambers for approximately 20 min for weighing and to allow cleaning and maintenance of the chambers.

Because all subjects had prior histories of key pecking, no preexperimental training was given. All subjects were exposed to the first condition in the first session. Birds R39 and Y2 were assigned randomly to an open economy in Condition 1, and Birds G46 and 886 were assigned to a closed economy in Condition 1. After the subjects had satisfied the stability criterion they were exposed to the same contingencies but under the other economic context. Component length was changed only after a subject had been exposed to both economies at that component duration.

Deprivation schedule. A subject that had just completed an open economy was, in the next session, introduced to a closed economy or a new component duration and a closed economy depending on the subject and the prior condition. For a subject that had just completed a closed economy, the mean weight taken from the last five sessions was designated as that subject's new ad-libitum weight. This subject was then placed on a deprivation regimen until it reached 80% of this new ad-libitum weight. Subsequent to the deprivation regimen, the subject was then exposed to an open economy or a new component duration and an open economy depending on the subject and the prior condition. Accordingly, Subjects R39 and Y2 were placed on deprivation regimens between changes in component duration, and G46 and 886 were placed on deprivation regimens and then exposed to the same component duration (see Table 1).

RESULTS

All data used for analysis represent the mean from the last five sessions in each condition. It can be seen in Table 2 that the number of reinforcers obtained per component was not affected systematically by component duration in either the open or closed economy. For all subjects the total number of responses emitted per component and the obtained reinforcers per component were consistently higher in the closed economy than in the open economy. This is not surprising because the closed economy sessions were much longer. The number of

sessions conducted for each condition, initial free-feeding body weight, and the mean body weight from the last five sessions in each closed economy condition are also shown in Table 2.

Figure 1 shows, for each subject, the relative rate of responding in the richer (VI 30 s) component as a function of component duration under open and closed economies. A nonparametric trend test (Ferguson, 1966) showed that across subjects the tendency for relative response rate to increase as components were lengthened from 10 s to 300 s in the closed economy, and the tendency for relative rate to decrease over the same manipulation in the open economy, were significant ($N = 4$ subjects, $k = 5$ conditions, $z = 2.38$, $p < .05$, closed economy; $z = 2.33$, $p = .05$, open economy). The data from the replications of the 10-s and 180-s component durations following the schedule reversal support the trend observed in the closed economy in two ways. First, relative response rate for all but 1 subject was higher at a component duration of 180 s than at 10 s; second, there was little difference between relative rate for the two replications. The absolute difference in relative rate across subjects in the two conditions with a component duration of 180 s was .03, and was .07 in the two conditions in which component duration was 10 s. Supporting evidence for the significant trend observed in the open economy is less clear. Although the absolute difference in relative rate across subjects for the two replications of component duration in the open economy was small (.03 and .04 for component durations of 180 s and 10 s, respectively), the direction in which relative rate changed as component length was changed was inconsistent with the results from the ascending series. Relative response rate increased as components were shortened for only Subject R39, whereas it decreased for the other subjects following the schedule reversal.

Figure 2 shows the group mean absolute rates of responding in the richer (VI 30 s) and leaner (VI 90 s) components as a function of component duration in the open economy (left panel) and the closed economy (right panel). For all subjects, higher rates were maintained during the component with the VI 30-s schedule of reinforcement than the component with the VI 90-s schedule regardless of component duration. Response rate in both components

Table 2

Total responses, total reinforcers, sessions per condition, and body weight (closed economy only) for each subject. The data represent the mean from the last five sessions in each condition.

	Component duration	Economy	Total responses		Obtained reinforcers		Sessions per condition	Weight (g)
			Red	Green	Red	Green		
R39	10	Open	1,115.0	496.4	66.8	22.2	37	686 (ad-lib)
	30		1,104.8	617.4	60.4	20.4	36	
	90		1,072.8	779.0	61.6	19.6	40	
	180		1,114.0	585.0	70.2	22.2	35	
	300		864.8	763.6	58.6	17.8	39	
	180		473.4	1,073.8	20.4	61.3	48	
	10		523.2	1,239.8	23.4	65.4	35	
	10	Closed	3,684.0	1,783.0	452.8	139.2	54	
	30		2,268.2	996.4	310.0	130.2	49	
	90		2,454.4	981.8	278.6	125.6	47	
	180		4,329.2	1,347.8	263.8	98.2	56	
	300		2,325.8	754.6	256.0	107.2	49	
	180		1,759.4	5,916.6	137.6	458.8	50	
	10		1,034.4	3,974.2	101.6	311.8	52	
Y2	10	Open	3,532.0	1,776.2	57.2	25.2	29	433 (ad-lib)
	30		2,409.4	1,239.4	51.8	21.4	37	
	90		2,716.8	1,664.8	49.0	19.8	35	
	180		3,046.4	2,252.8	58.6	21.8	35	
	300		1,370.0	894.4	46.8	19.0	30	
	180		1,138.0	2,122.2	23.1	53.2	29	
	10		1,031.6	1,009.6	24.0	55.2	31	
	10	Closed	10,107.6	7,406.2	438.4	185.4	39	
	30		2,742.8	1,412.4	313.8	133.6	42	
	90		2,565.2	1,438.4	295.0	144.4	53	
	180		5,219.8	1,342.4	350.2	120.4	36	
	300		3,185.4	1,665.6	216.8	124.4	41	
	180		4,510.4	12,031.4	184.4	445.0	50	
	10		1,829.2	4,123.8	162.1	375.3	40	
G46	10	Open	757.4	352.0	49.4	17.6	21	593 (ad-lib)
	30		1,755.6	971.8	47.2	19.8	28	
	90		2,228.4	1,325.8	47.4	19.4	25	
	180		1,655.0	867.4	44.6	16.2	30	
	300		2,206.6	1,523.4	47.2	17.8	32	
	180		377.2	1,067.2	15.4	46.6	28	
	10		388.4	1,071.0	17.4	40.0	31	
	10	Closed	3,507.2	2,255.6	297.0	139.6	45	
	30		6,925.8	1,841.2	225.6	77.0	51	
	90		5,432.2	1,426.0	199.4	75.2	39	
	180		5,682.2	1,064.6	237.2	80.0	43	
	300		1,803.2	719.4	229.4	107.4	37	
	180		1,007.4	4,962.4	75.4	257.8	52	
	10		1,623.2	4,107.8	89.4	243.2	46	
886	10	Open	1,336.6	824.4	59.8	23.2	30	431 (ad-lib)
	30		1,542.2	454.4	61.4	21.7	27	
	90		1,332.2	353.2	65.8	22.6	30	
	180		933.8	397.4	61.6	19.8	31	
	300		1,014.0	466.0	63.8	21.4	26	
	180		967.0	1,855.8	20.0	58.4	29	
	10		719.4	1,116.6	29.0	82.8	33	

Table 2 (Continued)

Component duration	Economy	Total responses		Obtained reinforcers		Sessions per condition	Weight (g)
		Red	Green	Red	Green		
10	Closed	1,212.6	678.2	198.6	90.0	47	437
30		2,385.6	600.0	287.6	115.2	51	430
90		1,928.0	598.2	299.2	119.0	49	432
180		2,133.8	500.2	254.6	87.4	43	435
300		1,868.4	353.4	252.2	85.2	62	430
180		319.2	2,110.8	81.6	261.2	48	435
10		424.8	2,345.4	93.2	237.6	37	430

was lower during the closed economy than in the open economy and was within the range found in other studies that have examined multiple-schedule performance with 24-hr sessions (Elliffe & Davison, 1985; Norborg et al., 1983). According to a nonparametric trend test, changes in absolute response rate in the richer and poorer components as a function of increasing component duration under an open economy were not significant ($z = 1.34$ and 0.61 , respectively, $p > .05$). In the closed economy, there was no evidence of a significant trend in absolute rate during the richer component as component duration was lengthened ($z = 0.24$, $p > .05$), whereas the tendency for absolute rate to decrease in the poorer component as component duration was increased was significant ($z = 3.55$, $p < .05$).

For each subject in open and closed economies, the undermatching (b) and bias parameters (a) from the generalized matching equation were estimated for those conditions in which the VI 30-s and VI 90-s schedules were reversed between components (Conditions 1 and 13, 2 and 14, 7 and 11, 8 and 12). To obtain these estimates the logarithmic transformation of Equation 1 was used. This is a linear function with a slope of b and y -intercept of $\log a$:

$$\log(P1/P2) = b \log(R1/R2) + \log a. \quad (2)$$

Estimates of the parameters were derived by simultaneous equations as suggested by Charman and Davison (1982, Experiment 3). These estimates are presented in Figure 3. The upper panel shows that there is no clear relation between the undermatching parameter of Equation 1 and component duration for open economy conditions (open points), whereas there is a reliable increase in the same parameter in the closed economy (filled points). The lower

panel shows estimates of the bias parameter. Although there appears to be a tendency for bias to covary in the same direction as changes in b under the closed economy, the absolute values of the bias parameter are small.

DISCUSSION

The main finding of the present study is that in 23.5-hr sessions (closed economy), subjects' response proportions overmatched reinforcer proportions to a greater extent with longer components, whereas there was no systematic effect of component duration on responding with 1-hr sessions (open economy).

The open economy conditions in which the component schedules were held constant as component duration was manipulated constitute a direct replication of the results of Shimp and Wheatley (1971) and Todorov (1972). Results of those studies showed that as components were shortened, relative rate of responding increased, absolute rate in the richer component increased while rate in poorer component remained invariant, and that relative response rate and relative reinforcement rate approached unity. Both the Shimp and Wheatley and Todorov studies were conducted under conditions comparable to the open economy conditions of the present study (i.e., short session length and deprivation regimens), but results of the present study provide only marginal support for the findings of these previous studies. Relative rate of responding decreased as components were lengthened; however, there was no systematic effect of component duration on absolute rate of responding in the richer or leaner components, and repeatability at the replications of the 10-s conditions was poor. This suggests that, despite the significant trend for relative rate to change as components were

Fig. 1. Relative response rate computed for the VI 30-s component as a function of component duration (in seconds) during the open economy (open points) and the closed economy (filled points). Points to the right of the data break in each graph are from conditions in which the schedules of reinforcement were reversed between components. The group mean is depicted in the bottom panel.

altered, this change could easily have been due to some other factors, such as extended exposure to a single reinforcer differential. This notion is further supported by absence of a short component effect. Figure 3 shows that there was no clear relation between values of the undermatching parameter from Equation

1 and component duration. These findings support the conclusions drawn by Charman and Davison (1982) about the transient nature of the short component effect. Indeed, the results from the current experiment are more consistent with the results from Experiments 2 and 4 of Charman and Davison, as well as

Fig. 2. Mean absolute rates of responding during the VI 30-s component (open points) and the VI 90-s component (filled points) as a function of component duration (in seconds) in the open and closed economies. Points to the right of the break in the abscissa of each graph are from conditions in which the component schedules were reversed.

those of others (McSweeney et al., 1986; White, Pipe, McLean, & Redman, 1985) rather than with those of Shimp and Wheatley and Todorov.

Nevertheless, the results from the open economy provide a background with which one can compare the results obtained under the closed economy of the present study. When component duration was manipulated in the closed economy the results, in all but one case, were quite different than those obtained in the open economy.

In the closed economy, relative response rate increased as components were lengthened. This trend was significant and was accompanied by a significant trend for absolute response rate in the poorer component to decrease over the same manipulation. Response rate in the richer component was not affected systematically by component duration (this is the only result shared by the two economies). These findings are inconsistent with previous studies that have examined the effects of component duration in open economy *mult* VI VI situations, but they are consistent with the only published study to examine the effects of component duration on response rate in a closed economy (Norborg et al., 1983). Norborg et al. showed that response rate in the component with the less demanding FR schedule remained invariant, whereas response rate during the component with the more demanding FR schedule decreased as component duration was lengthened. The effects of component duration on

absolute response rates in a closed economy when food delivery is dependent upon fulfillment of an FR or VI contingency are comparable. Because each reward in the richer and leaner components of the current study was not dependent upon a fixed number of responses emitted, the results of Norborg et al. were probably due to their use of a closed economy and not to their use of FR rather than VI schedules of reinforcement.

The finding that relative response rate increased as a function of increasing component duration may also provide an explanation for results from the only published study that has examined *mult* VI VI performance in a closed economy (Elliffe & Davison, 1985). In that study only one component duration was used (150 s), and it was suggested that closed economy multiple-schedule performance could be characterized by generalized matching exponents of 1.5 (overmatching). In the present closed economy, generalized matching exponents were found to increase for all subjects as component duration was lengthened, and at the longest component duration considered in this analysis (180 s) were consistent with an overmatching interpretation. Moreover, this analysis revealed that at the shortest condition duration considered (10 s), exponents for 3 of 4 subjects were consistent with an undermatching interpretation.

Because at approximately the same component duration used by Elliffe and Davison (1985) all subjects in the present experiment

Fig. 3. Estimates of the undermatching component b (top panel) and bias parameter a (bottom panel) of the generalized matching equation as a function of component duration (in seconds) for each subject in open and closed economies. The values of the parameters were derived by simultaneous equations.

overmatched whereas at the shorter component durations they did not, it is interesting to speculate whether the degree of overmatching evident in the Elliffe and Davison study would have been different had they used a component duration other than 150 s.

The data in Figure 4 show point estimates of the sensitivity parameter of the generalized matching equation from those conditions in the open and closed economies of the present study in which a single reinforcer differential was used. These data points were generated by assuming zero bias (a reasonable assumption for all subjects in the present study; see Figure 3) in the logarithmic version of the generalized matching law and solving the resulting equation:

Fig. 4. Mean point estimates of sensitivity as a function of component duration (in seconds) from the open economy (open points) and the closed economy (filled points).

$$a = \log(P1/P2)/\log(R1/R2). \quad (3)$$

Figure 4 shows that birds' sensitivity to reinforcement changed in the current experiment as a function of component duration, and this function was different for closed and open economies. Under closed economy conditions, point estimates of sensitivity are directly related to component duration.

But why does an increase in component duration lead to greater overmatching in a closed economy but has no effect in an open economy? Because the same subjects were used and the same contingencies of reinforcement were in effect in both the open and closed economies of the present experiment, the answer to the above question must lie in the formal procedures used under each economy. There are three differences between the open and closed economies as used in the present study: (a) differences in deprivation level, (b) differences in session length, and (c) the presence or absence of postsession food.

From Table 2 it can be seen that subjects' body weights in the closed economy were comparable to their free-feeding weights established at the onset of the study. Subjects were, therefore, presumably less deprived in the closed economy than in the open economy conditions in which an explicit deprivation regimen was used. This difference in deprivation, however, cannot account for the overmatching obtained in light of results from previous stud-

ies that have shown matching to be the limiting form of the relation between responding and reinforcement on *mult VI VI* schedules when there is little or no deprivation (Charman & Davison, 1983; Herrnstein & Loveland, 1974).

An account of the overmatching result of the present experiment with respect to differences in session length and the presence or absence of postsession food requires an explanation in terms of ecological variables. Recent work by operant psychologists, as well as field research and experiments conducted by biologists, on foraging and choice behavior have focused on optimality models of diet selection and patch-use patterns, which can be thought of as essentially the same type of problem (Pyke, Pulliam, & Charnov, 1977). One of the simplifying assumptions underlying optimality accounts of diet selection is that individual items or patches can be rank-ordered in terms of profitability, or the time it takes to extract the unit energy content from an item or patch; a second assumption is that prey items are encountered sequentially and randomly in time (Charnov, 1976). One of the main variables that influence optimal diet selection is the overall abundance of prey or patches (Fantino & Abarca, 1985; Fantino & Preston, 1988). In general, when resources are abundant animals will be selective, and only the more preferred prey types will be consumed; when preferred prey are encountered infrequently, as when resources are scarce, both preferred and less preferred prey are likely to be consumed when encountered. The open economy corresponds to generally scarce prey conditions and the closed economy to generally abundant prey conditions. Therefore subjects are likely to be more selective in the closed economy, thereby leading to greater overmatching in the closed economy.

The finding of consistent and replicable overmatching at long component durations in the closed economy suggests that our current understanding of multiple-schedule behavior is in need of refinement. Some authors have suggested that the use of sessions that comprise most of a subject's day are more naturalistic than short (1 hr) sessions (Baum 1972, 1974a) and, thus, allow a more thorough examination of the controlling variables of the strategies animals use for adaptive success in face of a changing environment (Collier & Rovee-Collier, 1983). Unlike other studies that have com-

pared the results of a closed economy against the literature on open economy findings, the present experiment compared the effects of open and closed economies within a single experiment and found that the results were differentially affected by economic context.

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