THE AGGREGATE IMPLICATIONS OF MACHINE REPLACEMENT: THEORY AND EVIDENCE

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Abstract

This paper studies an economy in which producers incur resource costs to replace depreciated machines. The process of costly replacement and depreciation creates endogenous fluctuations in productivity, employment and output of a single producer. We also explore the spillover effects of machine replacement on other sectors of the economy and provide conditions for synchronized machine replacement by multiple, independent producers. The implications of our model are generally consistent with observed monthly output, employment and productivity fluctuations in automobile plants. Synchronization of retooling across plants within the auto industry is widespread so that the fluctuations observed at the plant level have aggregate implications.

Keywords: retooling, productivity, seasonal cycles.

This paper investigates the aggregate implications of a non-convexity in technology: the firm's choice of technique. In particular, we study a machine replacement problem in which a firm must decide whether or not to install a new machine or continue to produce with an older, depreciated machine. We first characterize the solution to this problem for a single agent and then study the spillover effects of machine replacement on other aspects of economic activity. The paper concludes with extensive empirical evidence on machine replacement by automobile producers and its implications for monthly fluctuations in production, employment and productivity in manufacturing. For the most part, our analysis concerns seasonal fluctuations though the work is suggestive for business cycles as well.[1]

In general, the point of introducing non-convexities into macroeconomic models is two-fold. First, in order to induce the large fluctuations in economic activity observed in the data, macroeconomists often study stochastic models in which shocks to the environment induce variations in output and employment through intertemporal substitution effects. Non-convex economies present an alternative in that endogenous fluctuations may emerge in these environments.[2] Second, models with non-convexities can exacerbate the influence of shocks so that more of the variation in economic activity is explained within the model. In particular, small variations in exogenous variables may generate large responses in endogenous variables.

Here we consider the aggregate implications of the decision by a firm regarding the replacement of its machine: i.e. the machine replacement problem. In general, consider a firm for which the productivity of capital falls over time due to depreciation.[3] At any point in time, the firm can replace its capital with a new machine that is of current vintage. We view this as a discrete decision, replace or not, and one that has a resource cost.[4] In particular, our specification highlights the lumpy nature of the investment process stemming from a non-convexity in the adjustment process. Machine replacement naturally creates endogenous fluctuations in output which are positively correlated with productivity so that exogenous productivity shocks, as in a seasonal version of Finn Kydland and Edward Prescott [1982] for example, are not necessary to generate this positive correlation.

Section I presents our analysis of the Robinson Crusoe problem for this environment. Here we focus on the predictions of this model for employment, output and productivity. Section II considers the effects of shocks on the timing of machine replacement. We find that machine replacement is more likely when labor productivity is low or leisure is more valuable since the resource costs of replacing machines is less than if the machines are replaced in other times. This result highlights the potential link between seasonal fluctuations generated by machine replacement and the business cycle. Section III embeds this choice problem into a multi-sector general equilibrium model to illustrate the spillover effects of machine replacement on other sectors. In this section, we provide conditions under which firms will have an incentive to synchronize machine replacement so that this discrete decision is not smoothed by aggregation.

Finally, empirical evidence on the importance of machine replacement and other discrete activities is provided in Section IV. Our focus in the empirical analysis is the retooling/design cycle in the automobile industry. Sidney Fine [1963, page 5] describes the annual retooling in the auto industry as follows:

> "When the line was stopped at the end of the model run, the bulk of the production force would be laid off, new machinery would be installed, new dies moved into place, and the assembly line rearranged for the production of the new model."

This description matches the focus of our theoretical model. We begin our empirical analysis by looking at plant level data for some U.S. automobile manufactures for 1978-85. Among other things, these plants exhibit dramatic seasonal fluctuations in production induced by machine replacement. Further, machine replacement (or retooling) is synchronized in the summer months during the 1978-85 period. This synchronization, as well as a positive correlation between recessions and variations in employment for retoolings, is confirmed by an investigation of gross job creation and destruction in the auto industry using the Longitudinal Research Database. In addition, the intervention in the timing of model changeover by the Roosevelt Administration in 1935 provides a natural experiment for identifying the impact of machine replacement on seasonal fluctuations in output and productivity. We also relate the empirical findings of Joseph Beaulieu and Jeffrey Miron [1990] on the seasonal patterns of production throughout manufacturing to the spillover implications of our model.

I. Machine Replacement for Robinson Crusoe

We begin our analysis of the machine replacement problem (MRP) by considering the dynamic choice problem of a single producer, Robinson Crusoe (RC). This agent lives forever; consuming and producing in each period of life. Period t utility is given by $u(c_t) - g(n_t)$ where c_t is period t consumption and n_t is period t labor supply. Assume that $u(\cdot)$ is continuously differentiable, strictly increasing and strictly concave and that $g(\cdot)$ is continuously differentiable, strictly increasing and strictly convex. Further, assume $u(0)=g(0)=0$ and that $u'(0)>g'(0)$. RC is endowed with a unit of leisure time so $n_t \leq 1$ for all t and discounts the future at rate $\beta \in (0,1]$.

In each period, output, y_t, is produced from labor according to a linear technology of $y_t=z_t\theta_t n_t$, where θ_t indexes the current state of technology and $z_t \in \{k,1\}$ is an index of machine replacement. As discussed below, $z_t =1$ will indicate that machine replacement is not occurring and $z_t=k<1$ indicates machine replacement in period t. Average labor productivity is thus equal to 2_t when machines are not being replaced and equals $k2_t$ during replacement. Initially, we assume output cannot be stored so that $c_t=y_t$. We discuss the implications of allowing storage below.

The key to the specification of technology is the determination of 2_t. In each period, RC chooses whether or not to replace his machine. If RC chooses to replace the machine in period t, then $2_{t+1}=\hat{2}$. If RC chooses not to replace the machine, then $2_{t+1}=D2_t$ where $D,(0,1)$. This specification reflects the importance of capital depreciation, given by D. The process of replacement may include in it the production of the capital good and its installation. The cost of replacement is the reduction in the total and marginal product of labor during the replacement process.[5] The magnitude of this effect is determined by k. The one period lag in the replacement process contains both a time to build component and a time delay due to installation.

We also have assumed that in the event a machine is replaced, its productivity is independent of time -- there is no technological advance in this model. One could augment the model to allow the productivity of a new machine to grow with time. That is, suppose $\hat{2}_t=O\hat{2}_{t-1}$ where $O>1$ is the rate of technological progress and $\hat{2}_t$ is the productivity of a new period t machine. Further, one might argue that as the productivity of the new machines increase, the cost of installation might increase as well due to higher costs of producing and installing (including worker training) the new machines.

The cost of replacing the machine is modeled as a shift in the technology for producing consumption goods. This specification is intended to reflect the congestion effects of replacing machines on the production process and implies that, at the margin, producing more output is costlier when a machine is being replaced. Our point is to model the phenomenon that machine replacement increases cost so that production is lower during retooling periods.

Given this structure, the optimization problem of RC is

$$(1) \qquad \max_{\{n_t\},\{z_t\}} \sum_{t=0}^{\infty} \beta^t [u(c_t) - g(n_t)]$$

s.t.:

$$(1.a) \qquad c_t = z_t n_t \theta_t, \; z_t \in \{k, 1\}, \; \theta_1 = \hat{\theta} \text{ and}$$

$$(1.b) \qquad \theta_t = \begin{cases} \rho\theta_{t-1} \text{ if } z_{t-1} = 1 \\ \hat{\theta} \text{ if } z_{t-1} = k. \end{cases}$$

Denote the productivity of this period's machine, the state variable, by 2. If RC innovates, then his utility from this period onward is given by

$$(2) \qquad V^I(\theta) = W^I(\theta) + \beta V(\hat{\theta}) \quad \text{where}$$

$$(3) \qquad W^I(\theta) = \max_n u(nk\theta) - g(n).$$

So the value of innovating is given by the current utility from producing with a machine of productivity 2 <u>given</u> that the firm is replacing so that productivity is reduced by a factor of k. This current utility is given by $W^I(2)$. Let $n^I(2)$ be the optimal value of labor input when RC innovates and the state of productivity is 2. Once a machine is replaced, then RC's capital in the following period has productivity of $\hat{2}$. The value of that machine is given by $V(\hat{2})$. The function $V(\cdot)$ is defined below.

If RC does not innovate, then his utility is given by

(4) $$V^N(\theta) = W^N(\theta) + \beta V(\rho\theta) \quad \textit{where}$$

(5) $$W^N(\theta) = \max_n u(n\theta) - g(n).$$

Here $W^N(2)$ is the utility from producing with a machine of productivity 2 when the machine is <u>not</u> being replaced. Let $n^N(2)$ be the optimal value of labor input in the optimization problem given by (5). As we assume $u'(0)>g'(0)$, $n^j(2)>0$ for $2>0$ for $j=I,N$. Since $u(\cdot)$ and $g(\cdot)$ are assumed to be continuous, $n^j(2)$ is continuous and so will be $W^j(2)$ by the maximum theorem for $j=I,N$.

Finally, $V(2) = \max \{V^I(2),V^N(2)\}$. Note that both $V^I(2)$ and $V^N(2)$ are strictly increasing functions of 2 since $W^j(2)$ is increasing in 2 for $j=I,N$. Therefore $V(2)$ is strictly increasing in 2.

In each period, RC decides whether to replace or not by comparing the value of replacement with the value of continuing with the depreciated machine in the following period. We now consider some properties of the solution to this problem. The proofs for all results are available in an Appendix to this paper.

Lemma 1: If $cu'(c)$ is an increasing function of c, then an increase in 2 increases current utility more when the machine is not being replaced than when it is being replaced.

This result is a direct consequence of the loss of productivity during the replacement process. Since RC produces less when a machine is being replaced, the gain from an increase in 2 is lower. The assumption that $cu'(c)$ is an increasing function of c is a restriction on the curvature of $u(\cdot)$ needed to ensure that income effects do not dominate substitution effects. We maintain this assumption throughout the analysis.

Lemma 2: $dV^N(2)/d2 > dV^I(2)/d2$ for all 2.

Lemma 2 implies that, as a function of 2, $V^N(2)$ is steeper than $V^I(2)$ for all values of 2. This is an important property in terms of characterizing the value function $V(2)$ and hence the decision of RC on whether or not to replace the machine. The solution to Robinson Crusoe's optimization problem is characterized by,[6]

<u>Proposition 1</u>: If D is sufficiently close to 1, then there exists a critical level of 2, 2^*,(0,$\hat{2}$), such that RC replaces the machine iff $2\#2^*$.

Following a period of machine replacement, the technology parameter will decrease at a rate determined by D until $2\#2^*$. Then machine replacement will occur and 2 will be increased to $\hat{2}$. Ignoring integer problems, the number of periods between replacement is given by the T* solving $2^*=D^{T^*}\hat{2}$.

From $W^N(2)$, as given in (5), during the period between machine replacements, the level of employment will fall since $n^N(2)$ is increasing in 2. In fact, in the period of replacement, employment in the production of the consumption good will be at its lowest level both because 2 is at its minimum <u>and</u> because productivity is reduced by the congestion effects of the replacement process. In some cases, as with automobile plants, the replacement of machines requires that a plant shut down its operations. This could be modeled by assuming that k=0 so that productivity falls to zero during the replacement process.

This model generates a positive correlation between employment and labor productivity. In contrast to Kydland-Prescott [1982], these fluctuations are not driven by exogenous technological change. Instead the productivity variations arise quite naturally through the process of replacing machines. The implied frequency of output and productivity fluctuations is dictated by the parameters of the model. In practice, in the auto industry (for example) machine replacement occurs on an annual cycle with resulting seasonal fluctuations (see Section IV for further discussion).

With regard to employment and output fluctuations at the time of replacement, we find that

Lemma 3: $n^N(2^*/D)>n^N(2^*)>n^I(2^*)$.

Lemma 3 implies that employment in producing the final good is lower in the period of replacement than in the period just prior to replacement ($n^N(2^*/D)>n^I(2^*)$). Of course, the model overstates these employment effects somewhat since there are no labor resources devoted to the replacement process. If labor was required in the replacement process, then during the period of replacement there would be a shift in employment from production of consumer goods to the installation of new capital. The results of Lemma 3 will hold as long as the replacement process is not very labor intensive.

In the model, consumption fluctuates along with output since goods are not storable. The assumption of no inventories simplifies the analysis since we do not have to be concerned with two state variables. While we have not formally characterized the solution with inventories, our analysis of inventories in a general setting of non-convexities in the production technology (see Cooper-Haltiwanger [1992a]) suggests that the qualitative results of our analysis would carry through. The optimal policy would be to replace machines every T periods where D and k would be, as before, critical determinants of T. Inventories would be held between periods of replacement to smooth consumption relative to production. In particular, between replacement periods the path of consumption would be characterized by the Euler condition: $u'(c_t) = \$(1-*)u'(c_{t+1})$, where * is the rate of depreciation on inventories. Therefore, production smoothing would not be observed in this economy so that the variance of production would exceed that of sales. Further, the positive correlation between labor input and productivity found for the model without inventories would carry over to this setting. In sum, incorporating storage would sever the tight connection between consumption and output but would not change the qualitative implications for output, employment, and productivity.

While we have stressed the effects of machine replacement on productivity, replacement for changes in variety are probably important as well, particularly for the automobile sector studied in Section IV. In fact, as shown in Cooper-Haltiwanger [1992b], it is relatively straightforward to use the model to generate product cycles. In fact, in light of costs of shutdown and startup costs, there is an incentive for these two types of retoolings to be bunched.

We now consider extensions of the model in three important directions. First, we allow for shocks in the model to understand the relationship between the timing of the machine replacement and aggregate economic activity. Second, we evaluate the implications of the machine replacement problem for other sectors of the economy; i.e. we look at the spillover effects associated with this process and the timing of machine replacement when there are multiple producers. Finally, we look at the interaction of multiple producers solving the machine replacement problem.

II. Machine Replacement and Shocks

We introduce exogenous fluctuations in this economy by incorporating taste and technology shocks into the single agent problem. The point is to understand how the decision on machine replacement at the firm level is influenced by the state of the aggregate economy, represented by these shocks. In particular, let period t utility be given by $"_t u(c_t) - g(n_t)$ and let period t production be given by $y_t = z_t 2_t 8_t n_t$, where $"_t$ and 8_t are iid shocks to the marginal rate of substitution between consumption and leisure and the technology, respectively.

Denote " as the current period realization of the taste shock, and 8 the current period realization of the technology shock. If RC innovates, then his utility from this period onward is given by:

$$V^I(\theta) = W^I(\theta) + \beta EV(\hat{\theta}) \quad \textit{where} \tag{6}$$

$$W^I(\theta) = \max_n \alpha u(nk\theta\lambda) - g(n) \tag{7}$$

and E is the expectational operator. Similarly, if RC does not innovate then his utility is given by:

$$V^N(\theta) = W^N(\theta) + \beta EV(\rho\theta) \quad \textit{where} \tag{8}$$

$$W^N(\theta) = \max_n \alpha u(n\theta\lambda) - g(n). \tag{9}$$

As before, $V(2) = \max \{V^I(2), V^N(2)\}$. Under this specification, the analogues of Lemmas 1 and 2 and Proposition 1 hold.

The issue of interest is how the critical level of 2 is affected by the realizations " and 8. At the optimum,

$$\frac{dV^I}{d\alpha} = u(k\theta\lambda n^I(\theta)) \quad \textit{and} \quad \frac{dV^N}{d\alpha} = u(\theta\lambda n^N(\theta)).$$

As shown in Lemma 1, $n^I(2) < n^N(2)$. Thus $dV^I(2)/d" < dV^N(2)/d"$ since k<1.

Since machine replacement implies some loss of current production, machine replacement is most likely to occur during periods of low marginal utility. So 2^* is a decreasing function of ".

Now consider technology shocks. At the optimum,

$$\frac{dV^I}{d\lambda} = \alpha u'(k\theta\lambda n^I(\theta))\,k\theta n^I(\theta) \quad \textbf{\textit{and}} \quad \frac{dV^N}{d\lambda} = \alpha u'(\theta\lambda n^N(\theta))\,\theta n^N(\theta).$$

Given that substitution effects dominate, then, since $n^I(2) <$ $n^N(2)$ and $k<1$, $dV^I(2)/d8 < dV^N(2)/d8$. This implies that the higher is 8, the less likely RC will innovate in the current period. The intuition for this result is similar to that for taste shocks. High realizations of 8 indicate periods of high productivity and since machine replacement essentially requires some down time, this indicates that machine replacement will be more likely in low productivity periods. Therefore, 2^* is also a decreasing function of 8.

These result identify the link between machine replacement and current demand and cost conditions. Our analysis of iid shocks reveals that machine replacement is most likely in periods of low marginal utility of consumption, high marginal utility of leisure and/or low realized productivity. This suggests an interesting covariance between output and productivity fluctuations endogenously induced by machine replacement and output and productivity fluctuations exogenously generated by demand and cost shocks. This covariance implies a potential link between seasonal fluctuations endogenously generated by machine replacement and the stage of the business cycle. Viewed from this perspective, the machine replacement process acts as a potentially important propagation mechanism for adverse business cycle shocks.[7] This covariance involves testable implications regarding the timing of machine replacement. We return to this point in Section IV.

Allowing for inventory holding would mitigate the sensitivity of machine replacement to current demand conditions and exacerbate the sensitivity to current cost conditions. Inventories permit consumption smoothing in response to variations in tastes and facilitate production cost smoothing in response to cost variation. As noted by Martin Eichenbaum [1989], production cost smoothing implies that the timing of machine replacement would be even more sensitive to current cost conditions. However, as long as inventory holding costs are present, the qualitative effects described above would hold for both demand and cost variation.

The general principle that emerges is that replacement should occur when the productivity of labor is low and/or the value of leisure is high *but* the new machine should be in operation during periods of high productivity. For the iid case, the second effect is independent of the current state, (",8), so that only the opportunity cost effect is operative. Suppose though, that productivity followed a deterministic cyclical pattern. In that case, it is easy to see that replacement would occur at the end of the downturn when the opportunity cost of labor was low <u>and</u> the new machines would be operative at the start of the period of high productivity.

This discussion emphasizes the interaction between the state of the economy and the retooling decision through productivity loss during machine replacement. In more general models, other links between the replacement decision and the state of the aggregate economy may emerge. For instance, suppose that firms could hold inventories and that plants were often shutdown for periods of time due to excessive inventory accumulation. Further, suppose that shutting down and restarting plants entailed fixed costs. In this case, there is an incentive for firms to "bunch" shutdowns for retoolings with shutdowns for inventory adjustment during periods of low sales. As we shall see later, this is particularly relevant for automobile producers.

III. Decentralized Solution with Demand Linkages

In this section of the paper, we consider machine replacement in a multi-sector setting to investigate spillover across sectors and incentives for synchronization within sectors. These spillover effects are important because not all production activities are best described by the machine replacement problem and yet, as discussed further in our presentation of empirical evidence in Section IV, Beaulieu-Miron [1990] find that production in the entire manufacturing sector displays similar monthly variations as does the automobile sector. Further, the interactions of producers within a sector are important since we observe, for example, the synchronization of retooling among automobile producers.

As a historical note on the importance of spillovers and synchronization, there was an effort in 1934 to shift the new model year of the automobile manufacturers. The spillover effects from this are described by Charles Roos ([1937], p.468), who was the Director of Research at the Cowles Commission and formerly the Director of Research for the National Recovery Administration, as:

> "Late in 1934 automobile manufacturers reached an agreement to introduce the 1935 new models in October instead of December so as to separate the new-model and spring demand and make possible steadier operation. Simple as the plan is, its effects should be tremendous -- regularization of employment in the automobile industry and to a lesser extent in steel, lumber and allied industries, and, as may readily be verified by existing statistics, intensification of seasonal demand for transportation. Moreover, without any additional capital outlay, productive capacities of the automobile and steel industries will be increased, demand for housing in Detroit, Flint and other automobile-manufacturing towns will be regularized and bank deposits throughout the country be changed seasonally. Also, farm workers, who have been accustomed to finding winter employment in the automobile industry, will have to look elsewhere. But despite all these economic changes, the net effect on the national economy should be beneficial."

A. Spillovers with a Single Producer

Suppose there is a single producer that sells good 1 and consumes good 2. Denote by $u(Y_t) - g(n_t)$ the payoff to the monopolist in period t where Y_t is the level of consumption of the good produced in sector 2 and n_t is the level of work in period t. The function u(·) is assumed to be increasing and strictly concave while the disutility of work, g(·), is a strictly increasing and strictly convex function of n_t. The monopolist lives forever and discounts future utility at rate ß. Assume that the good produced by the monopolist can not be held in inventory.

The technology for producing good 1 is similar to that studied in the previous section of this paper. The production function for period t is given by $q_t=z_t 2_t n_t$. In this specification, 2_t equals $\hat{2}$ if the machine was replaced last period (z_{t-1}=k) and equals $D2_{t-1}$ otherwise (z_{t-1}=1), where D,(0,1) represents the rate of depreciation of the technology. As before, machine replacement reduces labor productivity as k<1.

Good 2 is produced by a large group of price taking agents who live for only a single period and only consume good 1.[8] Good 2 is not inventoriable and can be thought of as a service. For simplicity, assume there is a single, competitive sector 2 producer. The producer's preferences are given by $v(q_t^d) - h(y_t)$ where q_t^d is the period t consumption of good 1 by the competitive agent and y_t is the output of good 2. Assume that v(·) is strictly increasing and strictly concave, cv'(c) is increasing in c and h(·) is strictly increasing and strictly convex. Using the budget constraint for this agent, he chooses y_t to maximize

$v(y_t/p_t) - h(y_t)$. Implicitly this yields $y^*(p_t)$ as the supply function for sector 2 output which, by our assumptions, will be a decreasing function of p.

The monopolist chooses $\{z_t, p_t\}$ for t=0,1,2,... to maximize

$$\sum_{t=0}^{\infty} \beta^{t} [u(y^*(p_t)) - g(q^*(p_t)/(\Theta_t z_t))]$$

where $2_t = \hat{2}$ if $z_{t-1}=k$ and $2_t = D\ 2_{t-1}$ if $z_{t-1}=1$. In this objective function, $y^*(p_t)$ is the supply of the competitive firm and $q^*(p_t)$ is the monopolist's output. Since the monopolist meets demand forthcoming at the announced price, the monopolist must supply $q^*(p_t)/(2_t z_t)$ units of time to the production of goods. The solution to the monopolist's choice of machine replacement is given by

<u>Proposition 3</u> If the elasticity of demand for good 1 is non-increasing in p and D is close to 1, then there will exist a critical 2, 2^*, such that the monopolist will replace the machine iff $2 \# 2^*$.

This result corresponds to that for the Robinson Crusoe economy in terms of existence of replacement cycles. Moreover, machine replacement by the monopolist spills over to other activities in the economy through final demand linkages. Between periods of machine replacement, marginal cost increases since 2_t falls. As long as marginal revenue is increasing in price (decreasing in quantity), this increase in marginal cost will imply that prices will rise over time. Since output of the competitive sector is a decreasing function of the price set by the monopolist, as 2_t rises output of the competitive good and demand for the monopoly good will both fall. In this way, both sectors of the economy move together. Machine replacement creates congestion effects and thus higher marginal costs of production for the monopolist. This, in turn, induces competitive firms to reduce their output as well. In the period following replacement, there is a boost of productivity for the monopolist which leads to a price reduction: i.e. a sale. This sale induces an increase in output within the competitive sector.

A potentially counterfactual implication of this model is the predicted seasonal pattern of prices, particularly in light of well-known end of model year sales and the evidence on prices provided by Beaulieu-Miron [1990].[9] To the extent that there are relevant changes in the value of a product through the model year, the seasonal behavior of prices in our model would be modified. For example, in the automobile industry, one could argue that there is a premium paid for new models and that over the model year, marginal revenue shifts in along with marginal cost. This additional effect leads to ambiguity in the predictions of our model for the seasonal behavior of prices though quantities across sectors would still display positive covariance.[10]

There are a number of extensions of this structure worth considering. First, here we have stressed final demand linkages between the sectors. In Cooper-Haltiwanger [1992a], we considered factor demand linkages as the basis for the co-movement across sectors. This model could be amended so that the monopolist requires an input from competitive upstream producers leading to positively correlated output movements across sectors. Second, as demonstrated in Cooper-Haltiwanger [1990a, 1992a], storability of goods will weaken the contemporaneous spillover effects between sectors linked by either final goods or factor demand linkages. In the current environment, periods of machine replacement would coincide with less production of the good produced by the monopolist and, as long as there were some costs to the holding of inventories, less output by the competitive producers. A third possible extension would be to explicitly distinguish between the demands of firms and workers, as in Cooper-Haltiwanger [1990a]. In this case, during periods of machine replacement, employment would fall in sector 1, and the associated fall in labor income would induce workers in sector 1 to reduce their demand for good 2. This would reduce output and employment in sector 2, which in turn would feedback on the demand for goods produced by sector 1 output. Overall, positive comovement in employment and output across sectors is possible without large fluctuations in relative prices.

B. Machine Replacement with Multiple Producers

The previous section considered the spillover effects of machine replacement by focusing on the interactions of a single, non-convex firm on the remainder of the economy. This section focuses on the other dimension of multiple firms: the case of machine replacement with multiple producers each solving the machine replacement problem. This is important in that one might presume that the non-convexities at the firm level may be much less important as one aggregates. In fact, the smoothing by aggregation arguments implicit in general equilibrium models (e.g. Andreu Mas-Colell [1977]) with indivisibilities and/or non-convexities in preferences and technology rests on the observation that an economy with multiple agents sufficiently dispersed across indivisible choices behaves very much like a convex economy. The key in those results is the assumed dispersion or, applying that argument to our model, the assumed staggering of discrete decisions over time. Here we consider two classes of arguments bearing on the issue of timing of machine replacement with multiple producers.

One perspective on timing of discrete decisions, stressed in the work by Giuseppe Bertola and Ricardo Caballero [1990], is that the degree of synchronization is influenced by the correlation in the shocks influencing the tastes and preferences of the agents. In an economy in which there is no interaction between agents, so that each individual solves an optimization problem in which payoffs are independent of the actions of others, synchronization can still occur if shocks are highly correlated. Consider the economy described in Section II. If there were multiple producers solving the machine replacement problem and their values of "$_t$ were perfectly correlated, then clearly the entire economy would follow the solution of the representative agent. So, if July was a valued time for leisure by all agents, the model predicts that machine replacement will take place in that month.

According to Cooper-Haltiwanger [1992a] the timing of discrete decisions will also depend on the nature of the strategic interaction between the agents. Those results can be extended to the machine replacement problem in that following manner. Let B(2,2') be the payoff to a single producer using a machine with productivity 2 if all other firms in the economy produce using a machine of productivity 2'. Assume that this economy is symmetric in that all firms have identical payoff functions. As we are searching for conditions under which synchronization occurs, we assume that all other firms are behaving in an identical manner. The productivity of the machine is governed by (1.b) for each of the firms in this economy. To focus on the issue of timing of machine replacement, assume that replacement occurs every T periods. The issue is then whether or not a single producer will synchronize replacement with other firms.

<u>Proposition 3:</u> If $B_{12}>0$, then replacement will be synchronized in this economy.

This proposition rests on the condition that $B_{12}>0$, the condition of strategic complementarities found in many macroeconomic models and emphasized by Russell Cooper and Andrew

John [1988].[11] When this condition holds, the value to a single producer of increasing the productivity of his machine is higher when others have more productive machines. Cooper-Haltiwanger [1992b] analyze a product cycle model in which producers are led to synchronize the introduction of new models due to strategic complementarities from a marketing externality. If the introduction of new models and new capital are bunched, as argued earlier in this paper, then the marketing externality would imply the synchronization of machine replacement.

The importance of strategic interactions relative to the correlation of shocks is relevant for understanding the synchronization of replacement by automobile manufacturers in July (see Section IV). If final demand linkages are sufficiently strong across producers so that strategic complementarities are significant and/or there are significant non-convexities upstream from the automobile manufacturers, synchronization can emerge. Alternatively, following Bertola-Caballero [1990], one might argue that there are taste shocks for September cars, rationalizing replacement of machines in July with appropriate lags. Or, one might argue that July is a time of valuable leisure so that replacement in that period is appropriate. These taste shock explanations of the timing of replacement are consistent with the model presented in Section II of this paper. As Cooper-Haltiwanger [1992b] argue, relying solely on the high value of leisure in July requires an explanation of the fact that the shutdown for retooling occurred in early winter during the 1920s and early 1930s.

IV. Evidence

This section evaluates our theory using observations on the automobile industry. This is an important industry to study since, as demonstrated below, there are annual retoolings at both the plant and the industry level and the magnitude of the replacement cycle is related to the business cycle. Our data is from a number of sources. We use monthly plant level observations on output obtained from Ward's Automotive Reports (and related publications) to study the replacement cycle. The Longitudinal Research Database (LRD) provides plant level data on employment fluctuations on a quarterly basis. Finally, we examine the seasonal patterns of output and productivity for the auto assembly industry (SIC 3711) for both the interwar and post WW II periods. In presenting this evidence, we evaluate 4 key predictions in turn from our theoretical models.

A. The process of machine replacement creates lumpy and positively correlated fluctuations in output, employment and productivity at the plant level.

To characterize the importance of machine replacement for observed fluctuations in output at the micro-level, we examine the behavior of seven automobile plants in the United States for the period 1978-85 obtained from Ward's Automotive Reports.[12] The data provide information on monthly production, sales, the number of days the plant operated during the month, the number of shifts operating at the plant during the month, and the number of days that the plant was shutdown for retooling.[13] For the automobile industry, the shutdown of plants for retooling enables the producer to introduce new machines for the production of a new design and, at the same time, to install more productive capital. Both of these activities are key elements of our theoretical model.

Our analysis of this data is based upon the following accounting identity: monthly production is equal to the product of: (i) the number of cars produced per shift; (ii) the number of shifts per day; and (iii) the number of days the plant operates during the month.[14] The number of days that the plant operates can be further decomposed into the product of: (iv) the sum of the number of days the plant operates and the number of days the plant is shutdown for retooling; and (v) the ratio of the number of days of operation to the sum of days of operation and the days shutdown for retooling. We interpret variations in production driven by (v) as those associated with machine replacement.[15]

Figure 1 plots actual monthly production (PROD) and the implied monthly production when only days for machine replacement ((v) in the above decomposition)) is allowed to vary ($PROD^M$) for two of the seven plants.[16] The typical pattern for each plant is relatively volatile production often characterized by large, discrete changes. Strikingly, many of these discrete changes are induced by machine replacement.[17] The magnitude and duration of the reduction in production due to machine replacement varies considerably across plants and time. The timing of machine replacement is clearly concentrated in the summer months. The magnitude of the production loss due to machine replacement in a particular month tends to be larger when production in adjacent months is low. In particular, the magnitude and duration of the downturn in production is especially pronounced during the business cycle slump in 1982. This evidence supports the arguments in Section II discussing the potential interaction between the fluctuations induced by machine replacement and the stage of the business cycle.

The evidence presented in Figure 1 clearly illustrates the lumpy production changes induced by machine replacement. Further, the concentration of machine replacement in the summer months indicates that the role of machine replacement in the observed high volatility of production is closely tied to seasonal factors. To investigate this we estimated monthly seasonal coefficients (estimated via seasonal dummies as deviations from the mean) for monthly production (PROD), sales, and production allowing only machine replacement to vary ($PROD^M$). Key results from this exercise are reported in Table 1 (the coefficient estimates are reported in the working paper version of this paper, Cooper-Haltiwanger [1990b]).

Several striking patterns emerge from Table 1. First, the reported R^2s indicate that seasonal variation accounts for a sizeable fraction of the overall variation in production, sales, and production variation induced by machine replacement. Second, the seasonal variance ratio of $PROD^M$ and PROD reveal that seasonal production variation induced by machine replacement accounts for a large fraction of overall seasonal variation in production. The average of this ratio across the seven plants is 0.35. Third, for 5 of the 7 plants, the seasonal variance of production exceeds the seasonal variance of sales. At seasonal frequencies, these plants evidently do not exhibit production smoothing behavior. Since machine replacement is an important factor generating seasonal variation in production, the last two rows of Table 1 taken together suggest that machine replacement contributes to the fact that the seasonal variance of production exceeds the seasonal variance of sales.

Related evidence is provided in a recent paper by Timothy Bresnahan and Valerie Ramey [1992]. In a study of Ward's data on 50 Automobile plants for the period 1972-84, they found that on average machine replacement accounted for 33% of the total variation in days of operation of a plant.

To evaluate the implications of machine replacement for employment at the plant level, we use the quarterly production worker data at the plant level from the LRD for the period 1972:2 to 1988:4 to construct quarterly measures of gross job creation and job destruction for the auto (SIC 3711) industry (see Steve Davis, John Haltiwanger and Scott Schuh [1992] for further discussion of the data and the methodology for computing gross employment flows). Job creation for quarter t is the sum of all employment gains between t-1 and t at expanding and new establishments in the industry. Similarly, job destruction is the sum of all employment losses between t-1 and t at contracting and dying establishments. To express these measures as rates, we divide by sector size which is measured as the average of employment in the sector in period t-1 and t.

Job creation and destruction rates for the auto industry are plotted in Figure 2. Peaks and troughs are marked using the NBER Business Cycle reference date chronology for later use. Several striking patterns are illustrated in Figure 2. First, job destruction rates in the third quarter (May to August) are systematically very large while corresponding job creation rates are quite low. Third quarter job destruction rates average 16.5% while job creation rates average only 4.7%. Second, job creation rates in the fourth quarter (August to November) are very large while corresponding job destruction rates are low. Fourth quarter job creation rates average 17.9% while job destruction rates average 4.3%. The large third and fourth quarter magnitudes make clear the large quantitative impact the retooling period has on employment.

While we do not have direct evidence on productivity at the plant level, Anna Aizcorbe [1990] provides data on automobile plant level productivity for the 1978-1985 period. The data is monthly and based upon a match of Ward's data with BLS plant level data on employment. The employment data is the number of production-worker employees for the pay period which includes the twelfth of each month. Aizcorbe finds a positive correlation between line speed (the number of cars produced each hour) and the ratio of line speed to employment for each of the plants she considers (controlling for the number of shifts). In this analysis, line speed represents the maximal technically feasible output which can be produced from the current technology. Two points about this evidence are important for understanding its relevant implications for this analysis. First, line speed changes are coincident with model year changes -- that is, line speed only changes at the beginning of new model years. Second, Aizcorbe uses a frontier production function approach and restricts attention to periods of activity on the frontier. In this way, she is able to abstract from measurement problems that might arise in some months due to vacations and plant shutdowns. These points imply that the evidence on productivity from Aizcorbe provides information about changes in productivity across model years, not within model years. Given the coincidence of linespeed changes and model changeovers, this evidence indicates that model year changeover does raise productivity across model years which is consistent with our model.

It is interesting to note that replacement cycles at the firm level are not a recent phenomenon in the auto industry. In a study of General Motors during the 1920s and 1930s, Anil Kashyap and David Wilcox [1990] discuss GM's attempt at production smoothing given large seasonals in demand.[18] An important observation from that paper is the shutdowns for retoolings occurred annually for GM during this period and contributed substantially to the variation in production. As documented in Cooper-Haltiwanger [1992b], annual retoolings took place in most other automobile plants as well.

B. To the extent that parameter variations are common across agents or the reduced form payoffs of these agents exhibit strategic complementarities, periods of machine replacement by independent producers will be synchronized.

Several pieces of information point towards synchronization of the replacement cycle across automobile producers. First, the production data from Ward's depicts a concentration of machine replacement in the summer months. Using the seasonal coefficients underlying Table 1, the average pairwise correlation of the seasonal coefficients across plants is 0.47 for PROD and 0.39 for $PROD^M$. Second, the separation of net flows into gross job creation and destruction using the LRD data makes clear that there is substantial synchronization across plants in this retooling activity. In other words, given that almost all plants retool each year, the dramatic seasonal pattern of gross job creation and destruction would not arise if machine replacement was staggered across producers.

Third, the synchronization of plant level machine replacement manifests itself in industry level fluctuations in production, employment and productivity at seasonal frequencies. For this purpose, we examine monthly output and productivity variation for the auto assembly industry (SIC 3711) for both the interwar and post WW II years. The interwar years are of particular interest for this purpose since the timing of model changeover was changed as part of the National Industrial Recovery Act in an attempt to stabilize employment in the automobile industry. Prior to 1935, model changeover occurred in November and December. After 1935, model changeover occurred in the late summer and early fall. This policy intervention provides a natural experiment for identifying the influence of machine replacement on the seasonal patterns of production, employment and productivity. We use this policy intervention below to help discriminate between alternative hypotheses for the observed seasonal fluctuations.

For the post WW II years (1958:1-1990:7), we estimate OLS regressions of productivity and output growth on seasonal dummies. For the interwar years, (1923:1-39:12), we estimate OLS regressions on seasonal dummies and seasonal dummies interacted with an NIRA dummy (defined as 1 after 1935:1). Our findings for output and average labor productivity growth are summarized in Figure 3.[19]

For the post WW II period, we observe very large seasonal fluctuations in productivity and output growth. The largest fluctuations are the dramatic decrease in productivity and output growth in July and August and the subsequent dramatic increases in productivity and output growth in September and October. There is also a large swing in productivity and output growth at the end and beginning of the calendar year.

The large late summer, early fall swing is coincident with the model changeover period and is consistent with the predictions of our model. Alternatively, the large late summer/early fall fluctuations in output and productivity could be driven by the decrease in output associated with summer vacations and the accompanying decrease in productivity driven by either short run increasing returns or the mismeasurement of labor associated with vacations (i.e., the BLS establishment survey employment numbers we are using include all workers on the payroll for the week in question including workers on vacation). Some support for this hypothesis is present given the large fluctuations in output and productivity growth associated with the Christmas vacation period. Under this alternative hypothesis, the timing of model changeover is coincident with summer vacations (perhaps optimally) but has little impact on output and productivity growth.

Two pieces of evidence argue against this hypothesis. First, as is clear from the plant level analysis above, much of the seasonal fluctuations in output are in fact due to machine replacement, i.e. fluctuations in $PROD^M$ contribute significantly to fluctuations in automobile output at the plant level. Hence, it is not the case that the output fluctuations are due to summer vacation effects alone. Second, in terms of output and productivity, the evidence in the interwar years provides a means for distinguishing between the impact of summer vacations and model changeover. As noted above, the NIRA legislated a change in the timing of model changeover from winter to early fall. This provides a natural experiment for identifying the impact machine replacement relative to alternative factors such as summer vacations on productivity and output fluctuations. In particular, the seasonal patterns of productivity and output growth prior to 1935 during the summer and early fall should reflect the impact of summer vacations alone. As is clear from Figure 3, the pre NIRA seasonal fluctuations in productivity and output growth show relatively modest fluctuations in productivity and output growth in the summer and early Fall. However, once the timing of the model changeover was legislated by the NIRA in 1935, productivity and output growth fall dramatically in the late summer and rise dramatically in the late Fall.[20] It is striking that the post WWII pattern is essentially established starting with the 1935 intervention of the NIRA.

There is a bit of a phase shift in the timing of machine replacement in the the late 1930's and the post WWII period. From 1935 to 1939, machine replacement is concentrated in September and October while in the post WWII era machine replacement is concentrated in July and August.[21] Further examination of the NIRA intervention in terms of causes and consequences is provided in Cooper-Haltiwanger [1992b].

The evidence from the interwar years makes clear that summer vacations alone are insufficient to explain the observed seasonal fluctuations in productivity and output growth. The evidence clearly supports the hypothesis that seasonal fluctuations in productivity and output growth are connected to the timing of the model changeover. This does not rule out an important role for other factors that may interact with the model changeover effect.[22] In particular, during the model changeover period, both output and employment may be mismeasured. Part of the output during the model changeover period is the machine replacement process itself and part of the labor input at this time may be associated with installing and learning about the new production process. In addition, workers may opt to take (or even be forced to take) their (paid) vacations during the shutdown period due to machine replacement and this would generate additional mismeasurement of the labor input during these periods.

C. Machine replacement is most likely to occur during downturns where the resource cost of replacement is lower (due to low demand and/or high value of leisure) and just prior to upturns where the benefits of replacement are higher.

Figure 1 suggests that the magnitude and the duration of the downturn in production associated with retooling is larger in business cycle slumps. From the Ward's plant level data, there is further evidence of a connection between the replacement and the business cycles. The correlation between monthly production and monthly sales is quite high for all seven plants (average correlation 0.67). Variation in production due to machine replacement and sales is also positively correlated for all seven plants (average correlation 0.23): machine replacement is typically scheduled during periods of lower than average sales as suggested by our theoretical model. However, the time series for which we have consistent Ward's plant level data is quite short. This limits more formal statistical analysis with the Ward's data. To further investigate the impact of machine replacement on plant level behavior, we also examine the plant level data on employment in the Longitudinal Research Database (LRD).

A striking feature from the LRD, illustrated in Figure 2, is the extremely large rates of job destruction and creation in the automobile sector during the late 1970's and early 1980's. Over this period, the third quarter job destruction rate and subsequent fourth quarter job creation rates were often over 30%. This was obviously a time of tremendous restructuring and retooling in the auto industry. Since this was a period of an aggregate slump this suggests a connection between the magnitude of restructuring and the state of the economy.

To formally investigate this connection, we consider a simple empirical specification relating job creation and destruction rates to fixed quarterly effects and quarterly effects interacted with business cycle indicators.[23] Using NBER reference dates, the variable "recession" equals one in quarters for which any part of the preceding three months is associated with a recession. The results from this exercise are reported in Table 2. Two columns report results for autos only and the rightmost two columns report results for the total manufacturing sector for purposes of comparison. For autos, job destruction rises significantly in all quarters during a recession. The magnitude of the increase is actually largest in the first and second quarters but the quarter with the largest average job destruction rate during recessions is the third quarter. In sharp contrast, job creation rates for autos are not systematically related to the business cycle. This is an example of the results highlighted in Davis-Haltiwanger [1990] which emphasized that job destruction is much more cyclically sensitive than job creation. This latter result is evident in the columns for total manufacturing. It is interesting to note that, in the case of autos, job destruction is not more seasonally sensitive than job creation though it is at the business cycle frequency.

The relationship between job creation and the business cycle is less systematic for autos than for total manufacturing. The reason for this less systematic relationship seems to be the more pronounced seasonality in autos in both job creation and destruction during the business cycle slump in the early 1980s as seen in Figure 2. This episode works against the normal tendency for job creation to decrease during business cycle slumps.

D. To the extent that other activities in the economy are linked to those industries undertaking machine replacement (either through factor demand, final demand linkages or thick market effects), replacement in one sector will spillover to others.

Evidence on spillovers from machine replacement is implied by the evidence in a study of seasonality of manufacturing by Beaulieu-Miron [1991]. They find a strong decrease in activity throughout manufacturing during July. This is, of course, frequently a period of machine replacement for automobile plants. Beaulieu-Miron note that one explanation of the finding is the presence of synergies (strategic complementarities) that provide incentives for firms to synchronize reductions in activity. In Section III of this paper we find that the spillover effects of machine replacement can lead other sectors to decrease output and employment during periods of replacement. Beaulieu-Miron also note that labor productivity is positively correlated with output. This is also a property of the model we described in this paper and is true for the automobile industry too.

Beaulieu-Miron also report an expansionary phase in the Spring and a reduction of output during December. This was also true for our plant-level data and is not predicted by our model given that we concentrate solely on the replacement cycle. Finally, Beaulieu-Miron find that shipments of machinery and electrical machinery (see their Table 2) are relatively high in June. Assuming, a lag in the delivery/replacement process, this is consistent with our model.

The change in the timing of the model year induced by the NIRA examined above also provides a natural experiment for examining spillovers from the auto industry. Figure 4 presents monthly seasonal patterns of output growth for iron and steel and total manufacturing for the pre and post NIRA periods. The results indicate that the pattern of seasonal output growth for iron and steel was altered after 1935 -- output growth is lower in the first half of the year and higher in the second half. The same basic pattern emerges for total manufacturing.[24] This figure indicates the importance of automobile retooling on the timing of economic activity throughout manufacturing.

V. Conclusions

The point of this paper has been to study the discrete choice involving the replacement of obsolescent machines. When a single agent solves an intertemporal optimization problem which involves machine replacement, the solution displayed endogenous (seasonal) cycles with procyclical labor productivity. In a stochastic environment, machine replacement will occur near the end of economic downturns since the opportunity cost of displaced production workers is less than during good times. Through the spillover effects of machine replacement on other sectors, activity in other sectors will be positively correlated with the productivity of machines in the sector undertaking replacement. Finally, in the presence of strategic complementarities, multiple producers will synchronize machine replacement so that smoothing by aggregation will not occur. We also presented evidence: (i) of significant monthly output fluctuations due to machine replacement in the automobile industry, (ii) that these fluctuations matched some of the important seasonal fluctuations observed in manufacturing and (iii) that labor productivity is positively correlated with monthly output in the automobile industry.

A number of important issues remain. First, in our discussion of the decentralized economy, we focus on the two dimensions of timing separately: strategic interactions and the nature of the correlations in shocks to the agents' payoffs. It would be quite useful to consider a model in which both of these effects are present and then to attempt to identify the relative importance of these two influences on the timing of discrete decisions. This could be accomplished by merging the arguments in Cooper-Haltiwanger [1992a] and those contained in Section III of this paper with Bertola-Caballero [1990].

A second, and much harder issue, concerns the relative importance of the effects considered here for business cycles. We have offered evidence that the effects modeled here are important for seasonal fluctuations. Further, both our model and the evidence suggest potentially important links between the seasonal fluctuations generated by machine replacement and the stage of the business cycle.[25] One interesting way to evaluate the relative importance would be to produce a model of machine replacement that was capable of generating time series along the lines of Kydland-Prescott [1982] and then to compare the quantitative predictions of this model with those using exogenous shocks to generate fluctuations in a convex environment.

Third, there are some aspects of the seasonal fluctuations in productivity growth that are not well explained by our model. First, there is no evidence that productivity growth falls through the course of the model year. This is a prediction of our formal model, although an alternative version in which machine replacement is induced by obsolescence rather than depreciation is consistent with constant productivity growth within the model year. Second, the permanent increases in productivity across the model years (productivity growth averages 2.4% annually across model years in the 1958-90 period) is not fully accounted for by the increase in productivity in September and October. In fact, the increase in productivity growth in September and October essentially offsets the prior decline in productivity growth in July and August. The across model year increase in productivity is achieved throughout the course of the model year rather than abruptly at the time of model changeover. While these observations are not consistent with the formal model, adding some learning by doing, as in Peter Klenow [1992], might account for this. Further, the across year changes are minuscule relative to the within year seasonal fluctuations; it may be difficult to detect precisely the exact timing of the rather small increases in productivity across model years.

Finally, a complete investigation of the basis for changing the retooling period during the 1930s and its implications for the seasonal pattern of production would be quite interesting. In particular, why was the retooling period changed and why did it require collective action? Further, how did the change in the retooling period impact on the seasonal production pattern of other industries? Cooper-Haltiwanger [1992b] contains some analysis in this direction.

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TABLE 1

Nature and Sources of Production Volatility

	Plant						
R^2 for Seasonal	1	2	3	4	5	6	7
Regression of:							
PROD	0.21	0.12	0.33	0.34	0.20	0.17	0.17
$PROD^M$	0.45	0.15	0.47	0.47	0.62	0.25	0.23
SALES	0.31	0.23	0.49	0.44	0.25	0.09	0.09
Seasonal:							
$\frac{Var(PROD^M)}{Var(PROD)}$	0.25	0.35	0.14	0.64	0.80	0.11	0.15
$\frac{Var(PROD)}{Var(SALES)}$	0.66	0.90	1.98	1.04	1.32	3.06	3.34

Notes: The R^2 are based on regressions of the reported variable on 12 monthly dummies. The seasonal variance ratios are the respective ratios using the estimated seasonal coefficients from the regressions on seasonal dummies. Plant 1 = Belvidere, Plant 2 = Bowling Green, Plant 3 = Dearborn, Plant 4 = Linden, Plant 5 = Lynch Road, Plant 6 = St. Louis, and Plant 7 = Wixom.

Table 2: Quarterly Seasonal/Business Cycle Coefficent Estimates for Job Creation and Destruction

	Autos		Total Manufacturing	
Variable	JOB CREATION	JOB DESTRUCTION	JOB CREATION	JOB DESTRUCTION
QTR1	5.1	4.3	5.4	6.2
	(1.47)	(1.79)	(0.31)	(0.43)
QTR2	5.0	3.1	5.5	4.4
	(1.41)	(1.72)	(0.30)	(0.41)
QTR3	3.6	14.7	5.9	4.4
	(1.41)	(1.72)	(0.30)	(0.41)
QTR4	17.9	2.7	5.4	5.1
	(1.41)	(1.72)	(0.30)	(0.41)
QTR1xRECESSION	-1.0	14.8	-1.5	2.5
	(2.94)	(3.57)	(0.59)	(0.81)
QTR2xRECESSION	4.6	11.9	-0.2	3.0
	(2.91)	(3.54)	(0.59)	(0.80)
QTR3xRECESSION	4.7	7.6	-0.5	1.7
	(2.91)	(3.54)	(0.59)	(0.80)
QTR4xRECESSION	-0.4	7.1	-0.7	2.2
	(2.91)	(3.54)	(0.59)	(0.80)
Hypothesis Tests:				
All coefficients on QTR zero	0.0001	0.0001	0.0001	0.0001
All coefficients on QTR equal	0.0001	0.0001	0.6349	0.015

All coefficients on QTR*RECESSION zero	0.276	0.0001	0.0995	0.0001
All coefficients on QTR*RECESSION equal	0.344	0.375	0.505	0.742

Notes: The sample period for autos is 1972:2 to 1988:4. The sample period for total manufacturing is 1972:2 to 1986:4. Standard Errors in parentheses. Reported statistics for hypothesis tests are the marginal significance levels from relevant F-tests.

FIGURE 1

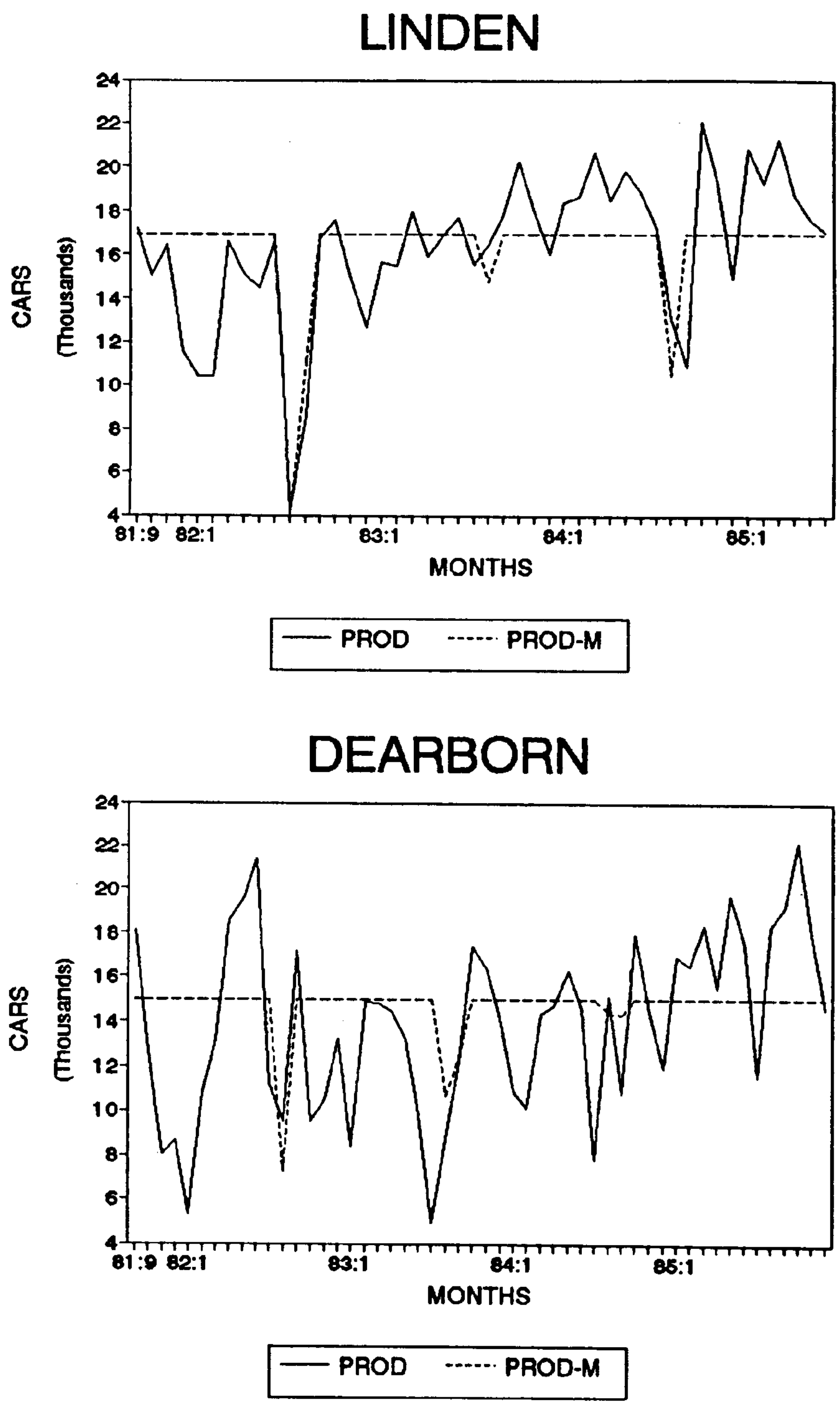

LINDEN
CARS
(Thousands)
24
22
20
18
16
14
12
10
8
6
4
81:9
82:1
83:1
84:1
85:1
MONTHS
PROD
PROD-M
DEARBORN
CARS
(Thousands)
24
22
20
18
16
14
12
10
8
6
4
81:9
82:1
83:1
84:1
85:1
MONTHS
PROD
PROD-M

Figure 2. Job Creation and Destruction
Autos, 1972:2-1988:4

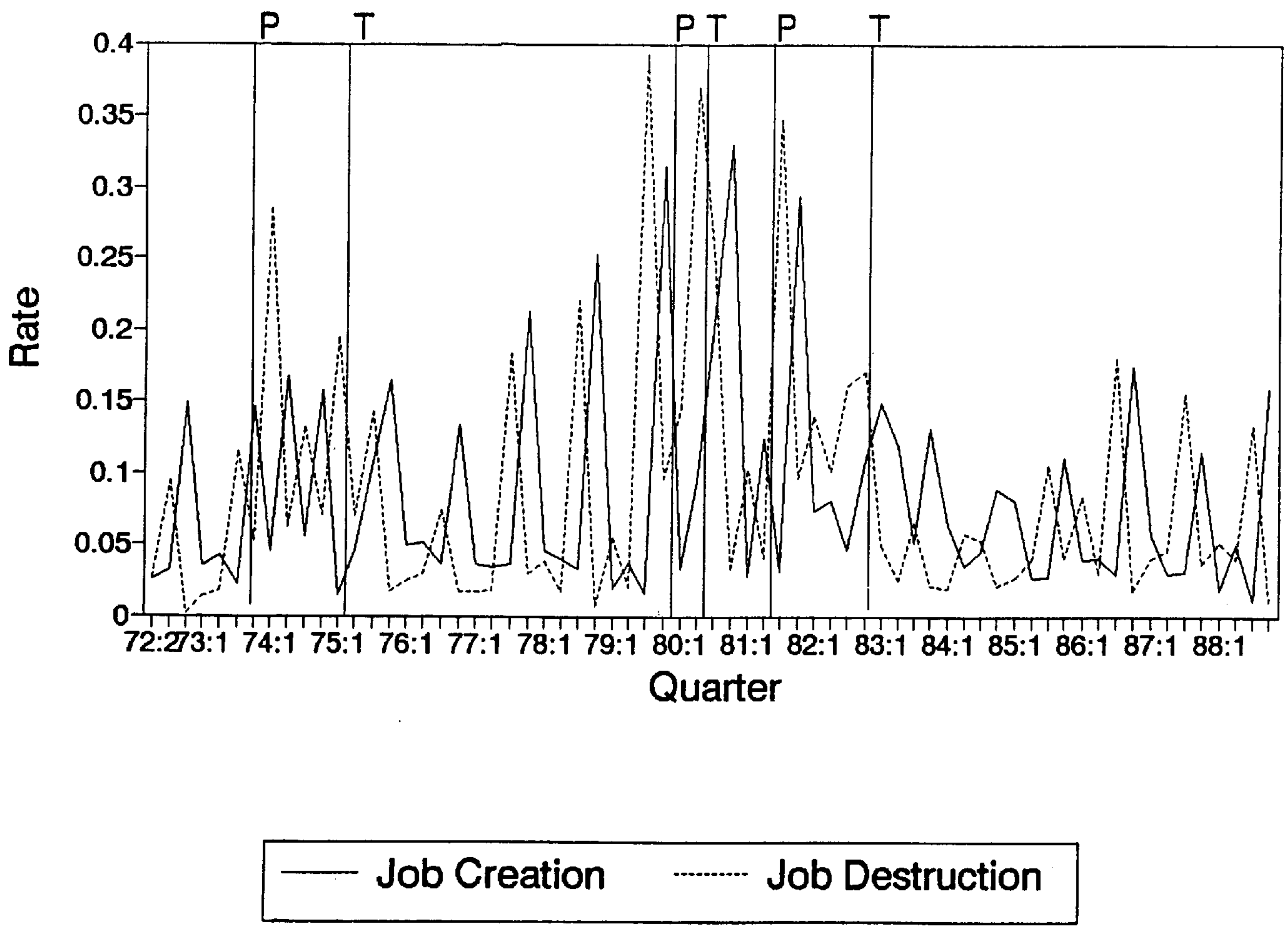


FIGURE 3 (AUTOS)

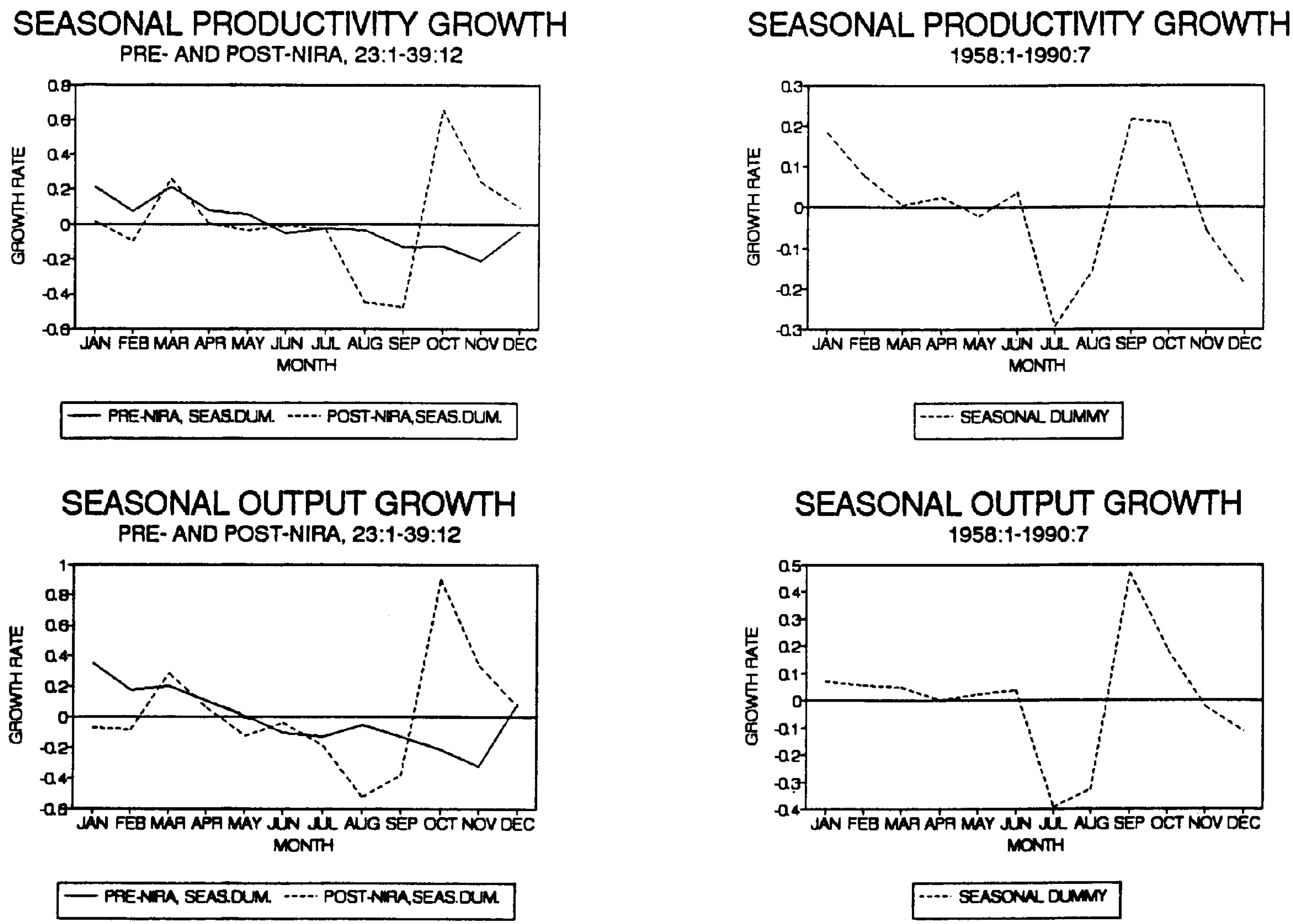
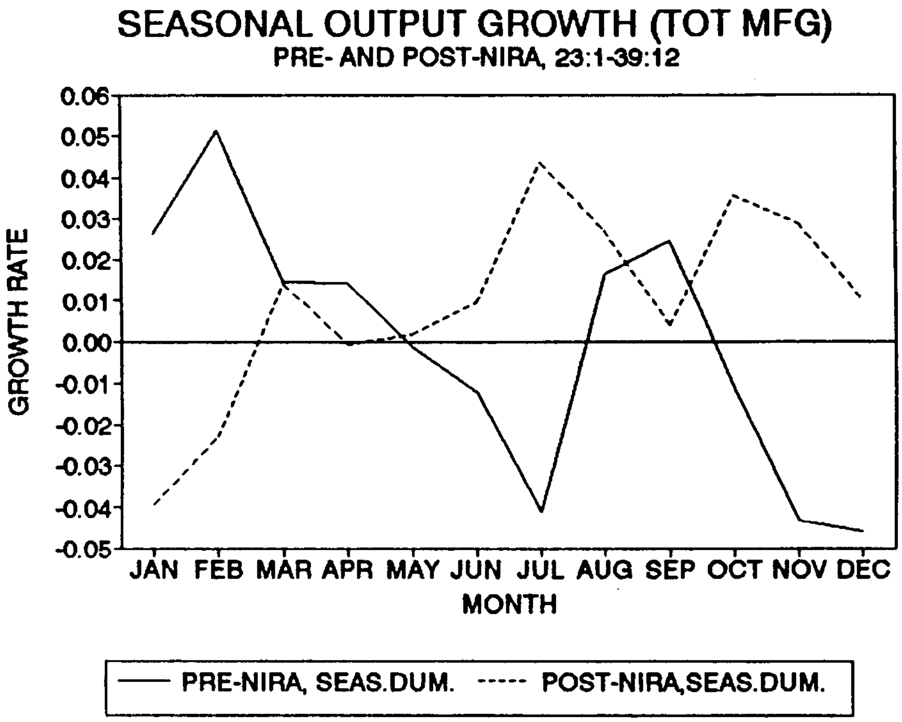
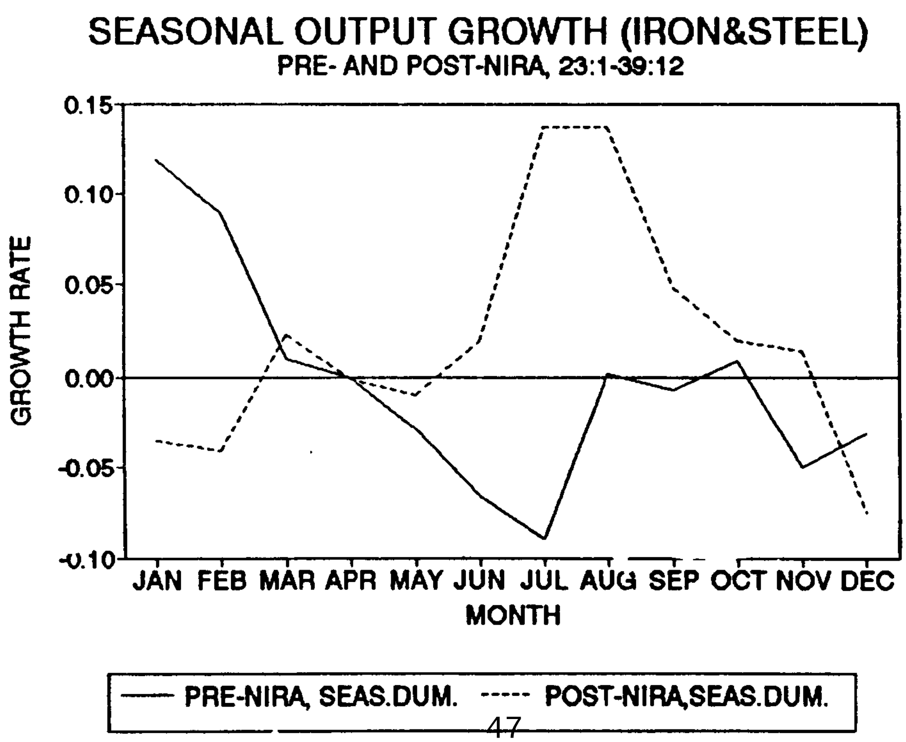


FIGURE 4


SEASONAL OUTPUT GROWTH (TOT MFG)
PRE- AND POST-NIRA, 23:1-39:12
GROWTH RATE
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTH
PRE-NIRA, SEAS.DUM.
POST-NIRA,SEAS.DUM.


SEASONAL OUTPUT GROWTH (IRON&STEEL)
PRE- AND POST-NIRA, 23:1-39:12
GROWTH RATE
0.15
0.10
0.05
0.00
-0.05
-0.10
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTH
PRE-NIRA, SEAS.DUM.
POST-NIRA,SEAS.DUM.

FOOTNOTES

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1. As argued in Robert Barsky and Jeffrey Miron [1989] and Joseph Beaulieu and Jeffrey Miron [1991], one can learn about business cycles through the study of seasonal fluctuations. Further, as argued below, our seasonal cycles are dependent on the stage of the business cycle. Finally, to the extent that some costs of adjustment are non-convex, our model can be applied to a study of more general investment decisions.

2. This point is discussed in Cooper-Haltiwanger [1992a] and Kevin Murphy, Andre Shleifer and Robert Vishny [1989]. In some sense, the fluctuations induced by non-convexities are similar to those produced in models of non-linearities in that for both types of models optimal choices can be very sensitive to variations in the underlying environment. Shleifer [1986] analyzes a model of cycles driven by the synchronized

introduction of new innovations.

3. The issue of replacement investment has received some attention, see, for e.g., Martin Feldstein and Michael Rothschild [1974] and Steven Nickell [1975]. The Feldstein-Rothschild analysis was mainly to understand the determinants of replacement investment and, in particular, to point out that conditions under which a constant replacement rate is optimal are quite restrictive. Using their terminology, our replacement entails _scrapping_ capital due to _deterioration_. In cases, considered below, where replacement allows the firm to introduce a more productive vintage, then our model is also about depreciation due to technological obsolescence. Nickell focuses on issues of maintenance and the optimal time to scrap a machine. Relative to these papers and others in the literature, we focus on lumpy replacement processes and on the implications of replacement for activities in other sectors of the economy.

4. Thus the paper differs from those in the large literature on convex costs of adjustment by assuming that replacement is a lumpy activity. See the interesting arguments for non-convex costs of adjustment in Rothschild [1971].

5. An alternative specification, explored in Cooper-Haltiwanger [1990b], allowed for a labor input into the replacement process instead of the effect of replacement on the production function specified here. The main results of the replacement cycle held in the alternative model though, when there is no effect of

replacement on labor productivity, total employment could be higher during replacement periods.

6. We are grateful to Marc Dudey for helpful discussions on this proposition.

7. The implied intertemporal substitution of machine replacement during slumps is similar to the reallocation timing arguments in Steve Davis and John Haltiwanger [1990] and the shake-out mechanisms discussed in Olivier Blanchard and Peter Diamond [1990] and Robert Hall [1991]. Ricardo Caballero and Mohammad Hammour [1991] also analyze the relationship between recessions and periods of reorganization. Essentially, these theories together suggest that business cycle slumps are times in which the economy takes a "pit stop" in order to retool, reallocate, and restructure.

8. This assumption is not crucial but simplifies matters so that we need not solve a static labor supply and an intertemporal optimization problem jointly. The main point of this section, that upon replacement the relative price of the monopolist's good will fall and stimulate production in other sectors, should generalize to a setting with competitive agents living more than a single period.

9. Table 8 of Beaulieu-Miron reports the seasonal pattern of growth rates in prices for, among other sectors, transportation equipment. There is no evidence here that prices rise through the model year. See the discussion in Olivier Blanchard and

Angelo Mellino [1986] concerning difficulties in estimating a price equation for the automobile sector.

10. The quantity predictions are an important aspect of this model given the observed co-movements in output and employment described by Beaulieu-Miron [1991] and Cooper-Haltiwanger [1990a]. See also the discussion in Fine [1963] about upstream linkages of the automobile industry and the resulting fluctuations caused by retooling.

11. Cooper-Haltiwanger [1990b] provides a broader discussion of macroeconomic examples for which this proposition holds in a machine replacement setting.

12. These data have been collected and tabulated from Ward's Automotive Reports and Ward's Automotive Yearbook. The data are available upon request. Note that the sample period varies across plants. This is because one of the criteria for the plants selected for analysis is that they are sole producers of a particular model. This facilitates linking the variables from Ward's. Some of the data in Ward's are available by plant (shifts, days, days retooling, linespeed) while others are available by model (production, sales).

13. Note that by sales here we mean final sales (not shipments to dealers).

14. The number of cars produced per shift depends on the line speed and the number of hours that a line operates during a shift.

15. Though it is possible that periods of retooling include shutdowns for the purpose of inventory adjustment as well. As we argued in III, shutdown and startup costs provide an incentive to bunch shutdowns for retooling with shutdowns for other purposes (e.g., inventory adjustment). While the data from Ward's clearly indicates the length of shutdown due to retooling we suspect that in periods of slow demand plants may report that they are down for retooling for longer than is necessary for the actual retooling process.

16. Plots for all seven plants are available in the longer working paper version of this paper, Cooper and Haltiwanger [1990b]. The patterns we discuss for Linden and Dearborn hold for all seven plants. In Figure 1, $PROD^M$ is generated by fixing (i), (ii) and (iv) in the above decomposition at their respective means.

17. The summer slowdown in production observed in these plots is consistent with the seasonality in manufacturing production reported by Beaulieu and Miron [1991]. Our findings here suggest that at least part of the pervasive summer slowdown is due to machine replacement/retooling effects.

18. The change in GM's production policy as well as the retooling process is described in some detail by Sloan [1964].

19. For the January 1923 to December 1939, the output series is monthly auto production (not seasonally adjusted) from <u>Ward's Automotive Yearbook</u> and <u>Automotive Facts and Figures</u>. The

employment (total hours) series comes from M. Ada Beny [1936] and R. Sayre [1940]. The output data for the period from January 1958 to July 1990 is from the industrial production index for passenger cars and trucks (industry #3711) and the total hours data is from the BLS establishment survey for the same industry group.

20. The null hypothesis that all the NIRA interaction coefficients are zero is rejected at the 1% level for both the productivity and output growth equations.

21. The hypothesis that the seasonal pattern of growth rates is the same in the late 1930s and the post WWII period is rejected at the 0.001 level. This is not surprising given the observed one month phase shift of the changeover period. The point we want to emphasize is that the qualitative seasonal pattern that began with the NIRA intervention persists through the present.

22. Ben Bernanke and Martin Parkinson [1991] attempt to distinguish two effects relevant here, increasing returns and labor hoarding. They find some support for the labor hoarding hypothesis as well as some evidence in favor of increasing returns (see the coefficient estimates in their Table 3). R. Anton Braun and Charles Evans [1991] find evidence of both increasing returns and labor hoarding in their investigation of quarterly, non-seasonally adjusted, U.S. data.

23. The idea that the seasonal cycle varies systematically with the business cycle has also been recently investigated by Eric

Ghysels [1991] and Stephen Cechetti, Kashyap and Wilcox [1992]. In particular, the latter finds that seasonals are more pronounced in downturns which is similar to the results reported here.

24. The null hypothesis that all the NIRA interaction coefficients are zero is rejected at the 5% level for total manufacturing and 10% level for iron and steel. For the latter, the months of August and January have significant interaction.

25. Additional recent papers that examine related issues include Satyajit Chatterjee and B. Ravikumar [1992] and Braun and Evans [1991].