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EVIDENCE ON MACROECONOMIC COMPLEMENTARITIES

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ABSTRACT

This paper provides empirical evidence on macroeconomic complementarities, a restriction on the nature of interaction between individuals in a multi-agent setting. These models imply that activities across agents will be positively correlated, that discrete decisions will be synchronized and that disturbances will be magnified and propagated. The paper shows that these implications are consistent with aggregate observations as well as some microeconomic evidence. Further, looking at certain historical episodes, such as the NIRA, as well as seasonal fluctuations provides additional support for models with macroeconomic complementarities.

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Evidence on Macroeconomic Complementarities

I. Introduction

Models with various forms of strategic complementarity have provided numerous insights into the nature of aggregate fluctuations. The term strategic complementarity means that the optimal action of one agent is an increasing function of the actions of others.[1] This paper emphasizes macroeconomic complementarities so that the optimal choice of an individual increases with some measure of the aggregate state of the economy rather than the actions of any single agent. From the perspective of individual choice, there is a "macroeconomic foundation of microeconomics" at work.

The theme of complementarity is simple enough: "If others work harder so will I." Yet this form of interaction across agents provides a rich theoretical basis for generating aggregate phenomenon, including the possibility of multiple equilibria and a source for the magnification and propagation of underlying exogenous shocks. The multiple equilibria that can arise in environments with strategic complementarity, along with the existence of positive spillovers, give theoretical content to the often expressed theme that economies can become stuck at an inefficient equilibrium. Put differently, there are equilibrium outcomes with $100 bills lying on the sidewalk because it takes the coordinated effort of many agents to reap these gains. Besides the multiplicity of equilibria, the magnification and propagation of shocks is important in understanding some of the empirical aspects of aggregate fluctuations.

The extant literature has brought to light the numerous avenues of interaction in an economy that serve, in theory, as sources of macroeconomic complementarity. Recent empirical work has sought evidence of the presence of complementarity in production and matching relations as well as the implications of complementarity in other aspects of economic relations.

The purpose of our paper is to synthesize these developments. First, we bring together some of the major propositions arising in the theoretical work on macroeconomic complementarities with the evidence. Second, the paper presents empirical evidence on this class of models.

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[1] See Cooper-John [1988] for a discussion of strategic complementarity in macroeconomic models.

To facilitate this synthesis, the paper begins with a brief review of the main features of a model economy with complementarity. We highlight three main propositions: positive comovement of output and employment across sectors over the business cycle, synchronization of discrete choices and the propagation of shocks over time. Building on these results, the following section describes empirical work that evaluates these predictions. This includes direct estimates of production relations with technological externalities as well as assessments of how well models with complementarities match observations of aggregate fluctuations.

This exercise provides two types of insights into models with complementarities. First, this class of models is quite capable of matching key observations of business cycles: comovement across sectors of activity, positive serial correlation and consumption smoothing relative to investment and output. Second, it is possible to distinguish models with complementarities from competing models by identifying key parameters and by focusing on historical episodes (such as the National Industrial Recovery Act) and times series frequencies (such as seasonal cycles) which create a basis for the natural identification of the effects stressed by these models. In this case, we find additional support for the models with complementarities.

It is important to emphasize that our focus is on the role of complementarities in aggregate fluctuations at high (business cycle and seasonal) frequencies. Complementarities are potentially important in accounting for low frequency differences in growth rates across countries, regions and time. Identifying and characterizing the role of such complementarities is a growing literature beyond the scope of this paper.[2]

II. Basic Theoretical Propositions

A. Models with Complementarities

Cooper and John [1988] provides a framework for analyzing static interactions in which strategic complementarity is important. A game theoretic treatment of these results in more general environments is provided in Vives [1990] and Milgrom and Roberts [1990]. Finally, as discussed below, there are a number of

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[2] On a broad conceptual basis, the complementarities that operate at high and low frequencies are clearly related. However, the precise connection is far from clear. For example, external returns to specialization are often cited in the growth and development setting. Changes in the degree of specialization are, however, unlikely to change much over the business cycle. Understanding the connection between complementarities at high and low frequencies is a topic of obvious interest that we leave for future research.

papers that go beyond the static model to explore the dynamic implications of complementarities. Here we present a fairly abstract dynamic model as well as an explicit example to highlight key theoretical propositions.

To introduce basic ideas, suppose that the period t payoff of a given agent depends on the effort (e^i_t) of the agent, on the aggregate level of activity from the previous period (E_{t-1}) and the level of aggregate effort in period t, (E_t). Assume that payoffs in period t are a continuously differentiable function, $\sigma(e^i_t, E_t, E_{t-1}, \theta_t)$, where θ_t represents the period t shock to the economy.[3] In each period, agents maximize their current payoff given the level of activity from the previous period, the current shock and the level of effort put forth by other agents in this period. Individuals are assumed to be small so that they perceive no influence of their own actions on the aggregate state of the system in the current and the future periods. In this sense, this is a model of interactions between the individual and aggregate variables. Since there are no state variables that an individual agent can control, this is a static optimization problem. Given the state of the system (E_{t-1}, θ_{t-1}), there will exist a symmetric Nash equilibrium with the choice of each agent given by $\xi(E_{t-1}, \theta_{t-1})$.[4]

Assume that $\sigma_{11}(e^i_t, E_t, E_{t-1}, \theta_t) < 0$, $\sigma_{12}(e^i_t, E_t, E_{t-1}, \theta_t) > 0$ and $\sigma_{13}(e^i_t, E_t, E_{t-1}, \theta_t) > 0$ over the entire domain of these functions. These restrictions imply that both contemporaneous and dynamic complementarities are present. That is, the optimal choice of an individual agent is an increasing function of current and lagged aggregate effort levels. Further, we assume, without loss of generality, that $\sigma_{14}(e^i_t, E_t, E_{t-1}, \theta_t) > 0$ so that increases in θ_t induce agents to put forth more effort in period t.

The presence of complementarities has two implications for this aggregate model. First, there may exist multiple equilibria indexed by the level of activity. Consider a static setting in which there are only contemporaneous complementarities. As discussed in Cooper and John [1988], this includes environments with production externalities, search externalities and imperfect competition. In this case, the existence of contemporaneous complementarities can lead to multiple symmetric Nash equilibria. Under the additional assumption of positive spillover, $\sigma_2(e^i_t, E_t, E_{t-1}, \theta_t) > 0$, these equilibria are Pareto-ordered and are inefficient.

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[3] Here we do not consider idiosyncratic shocks.

[4] An existence proof, given the current values of the state variables, would follow that provided by Cooper-John [1988] and will not be presented here.

The presence of the lagged effects influences the equilibrium analysis in two ways. In some cases, the multiplicity of equilibria in the static game translates into multiple steady state equilibria. The dynamics in the neighborhood of these equilibria may be quite rich, including the possibility of sunspot equilibria discussed, for example, by Chatterjee, Cooper and Ravikumar [1993] and Benhabib and Farmer [1992]. Further, the set of equilibria of the stage game (i.e. the game within a period given the state of the system) may vary with E_{t-1} so that the economy can move between regions of unique and multiple stage game equilibria.

Second, these complementarities influence the comparative statics properties of the economy. As stressed by Cooper and John [1988], the existence of contemporaneous complementarities leads to multiplier effects. Further, shocks in period t increase the level of activity and hence the state variable for the following period. The presence of the intertemporal complementarity implies that these increases in activity will be propagated over time.

There are now numerous examples in the literature of complementarities and the point of this paper is not to provide another catalogue of these environments. Notable models in the literature introduce some form of externality in the production process (e.g. Bryant [1983], Weil [1989], Durlauf [1991]) so that increases in the level of activity of other agents increases the productivity of a representative agent. In the models of search and matching (e.g. Diamond [1982], Howitt [1985], Howitt and McAfee [1988]), thick market externalities exist so that in times of high activity it is easier (cheaper) to find a trading partner and thus reduced "trading costs" induces the high level of activity. Finally, complementarities arise in multi-sector models of imperfect competition (e.g. Hart [1982], Weitzman [1982], Heller [1986], Kiyotaki [1988]). Here multiple Nash equilibria can arise due to variations in the elasticity of demand so that at low (high) levels of activity the demand function facing an industry is relatively inelastic (elastic) or through the existence of a non-convexity in the technology.

In this paper, our objective is to synthesize the various empirical contributions with regard to the implications of these models. While the theoretical propositions that we evaluate are found in many models with complementarites, we will often find it necessary to have a specific example to illustrate key points.

To do so, we consider a specific economy, drawing on Bryant [1983], in which the complementarity is present through a production function. We use this example, termed the production externality model, extensively since it has received the most attention in the empirical literature.[5] Assume that period t output by agent i is given by

$$y_t^i = \theta_t^i (e_t^i)^\alpha Y_t^\epsilon Y_{t-1}^\gamma \tag{1}$$

where α measures the returns to scale for an individual agent, ϵ is the contemporaneous technological spillover and γ measures a dynamic complementarity. Here the technology spillovers are modeled by a dependence of individual productivity on the average level of output in the current period (Y_t) and in the past period (Y_{t-1}).[6] The technology shock to agent i is given by θ_t^i which contains both an aggregate and an idiosyncratic component. This technology is supplemented with the preferences of an agent over consumption and effort given, for example, by $y_t^i - (e_t^i)^2/2$ where the consumption and production of the agent are equal.

Given the current state of technology and the past level of output (Y_{t-1}, θ_t), the effort level of each agent is determined in the Nash equilibrium. Note that in this economy there is no capital stock under the control of an individual agent so that the optimization is purely static. The evolution of the system is governed by the endogenous dynamics induced by the dependence of outcomes in period t on previous levels of activity and on the serial correlation of the technology shock. We return to specific properties of this economy below.

The issue of particular interest for this paper is to better understand the empirical implications of models with complementarities. From the perspective of aggregate fluctuations, how do these models explain leading empirical regularities and do they provide new insights into the anomalies of existing models? To investigate these questions, we derive a number of key themes that arise in models with strategic complementarity in this section of the paper and then summarize evidence on them in the remainder of the paper.

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[5] In fact, a creative interpretation of this formulation accommodates both a model of monopolistic competition in which demand functions depend on aggregate levels of activity (Blanchard and Kiyotaki [1988]) and models in which transactions costs depend on the level of aggregate activity (Howitt [1985]).

[6] In contrast to the example given above, the complementarities here arise through output instead of employment (effort) levels.

B. Positive Comovement

The first proposition characterizes the nature of individual responses to either individual or common disturbances. The proposition points to one of the key implications of the theme that agents work harder when others do: choices should be positively correlated across agents. For macroeconomics, when the effort choice is viewed as output or employment, the proposition indicates that positive correlation across agents in these variables is predicted by models with complementarities.

Proposition I: Positive Comovement: In the presence of strategic complementarity, choices will exhibit positive comovement across agents.

Cooper and John [1988] emphasize the comparative static properties of a model with two agents in which strategic complementarity is present. Then, common shocks elicit positively correlated variations in the activity levels of the agents. The comparative statics, as emphasized by Cooper and John, will include a magnification of the original disturbance due to the presence of complementarities. Further, a shock to one agent which increases his activity will lead the other to choose a higher level of activity as well due to the presence of strategic complementarity. In this sense, sector specific shocks also lead to positive comovement.

In the production externality model, suppose that there are no intertemporal linkages ($\gamma=0$) and constant returns to scale ($\alpha=1$). In this case, the reduced form for effort is

$$e_t^i = \theta_t^i Y_t^\epsilon \tag{2}$$

so that the individual responds to both the technology shock and to the increase in productivity induced by variations in average output, Y_t. The latter effect, of course, is governed by the contemporaneous production spillover, ϵ. Observed comovement in employment and output across such an economy would reflect both this complementarity and the common sources of variation to technology. Sector specific shocks will, through an influence on aggregate output, lead to an increase in activity by producers in other sectors. Through this contemporaneous production externality, other sectors of the economy respond thus creating positive comovement of employment and output.

A more dynamic formulation of this point appears in Cooper and Haltiwanger [1990]. They consider a two period, two sector economy. One of the two goods can be held in inventory and this provides the intertemporal link in their economy. Shocks to one sector in the first period lead to contemporaneous positive comovement in employment and output in the other sector. This arises not from the presence of technological spillovers but rather due to the fact that a fraction of the agent's income in one sector is spent on the other. Due to the presence of inventories, these shocks are propagated over time and positive comovement arises in the second period as well.

The demand spillovers used in Cooper and Haltiwanger [1990] and other models of imperfect competition stress final demand linkages. Alternatively, as in Long and Plosser [1983], factor demand linkages through a production process can also yield positive comovement across sectors of activity.

In the empirical section, we focus on comovement at both seasonal and business cycle frequencies. The evidence we provide documents the extent to which sectoral output, employment and prices are positively correlated at these two frequencies. A finding of positive comovement is certainly consistent with a model where strategic complementarity interacts with sectoral shocks and is also consistent with a model in which there are common shocks. We therefore attempt to distinguish common shocks from sectoral shocks in the empirical analysis by isolating frequencies at which the existence of common technology shocks seems less plausible.

C. Synchronization of Discrete Choices

Some models of complementarities use the existence of discrete choices to generate multiple equilibria.[7] The intuition for this comes from the Diamond [1982] model in which agents choose whether or not to undertake a costly production opportunity. In other settings, agents must decide on initiating a production run, introducing a new innovation, changing a price, running more than one shift, etc. The discreteness of the choice space provides a tractable means of creating jumps in reaction curves and thus multiple crossings.

In addition, ongoing work, for example Caballero-Engel [1993], has indicated the rich aggregate implications of discrete choices at the microeconomic level. These applications include price setting processes,

[7] Chatterjee and Cooper [1988] provides an abstract model of participation externalities that highlights discrete choices as a source of multiplicity.

job creation/destruction and durable goods purchases.[8]

An important question is then whether these discrete choices at the individual level are completely obscured by the aggregation process. In general equilibrium analysis, this theme of "smoothing by aggregation" is used to generate an equilibrium for a non-convex economy. While idiosyncratic shocks certainly create a basis for some staggering of discrete choices, aggregate fluctuations are usually associated with large movements in discrete microeconomic variables, the leading example being durable purchases by firms and consumers. The following proposition links the presence of strategic complementarity to the desire of private agents to synchronize discrete decisions.

Proposition II: Temporal Agglomeration : In the presence of strategic complementarity, agents will have an incentive to synchronize discrete decisions.

Hall [1991a] coins the phrase "temporal agglomeration" to stress an important property of models with strategic complementarity: agents have an incentive to bunch discrete decisions. This bunching of discrete decisions implies that aggregate fluctuations can potentially mimic the micro fluctuations induced by micro nonlinearities -- i.e., microeconomic nonconvexities can have aggregate fluctuations.

As an example of Proposition II, consider a very simple game of timing, presented in Cooper and Haltiwanger [1992], to better understand the incentive to synchronize discrete decisions. Consider an infinitely repeated noncooperative game played by two agents, indexed by $i=1,2$. Player 1's payoffs for period t are given by $\pi^1(y(t),z(t))$ where y(t) (z(t)) is agent 1's (2's) period t endowment. Player 2's preferences are defined analogously. Suppose that the endowment process fluctuates so that each agent has a high quantity, H, in one period followed by a low quantity, L, in the next and then the process repeats. Agents are assumed to discount the future at rate β. Further, assume that goods are not storable.

The agents play a game of timing in which they choose whether to have their period of high endowment in even or odd periods. That is, the strategy space for each agent is {E,O}. For example, if both

[8] For example, see Caballero and Engel [1991] and the references therein on price setting examples, Davis and Haltiwanger [1992] and Hamermesh [1989] stress the importance of lumpy adjustments in employment, Caballero [1993] and Eberly [1992] emphasize adjustments of consumer durables and Cooper and Haltiwanger [1993a] focus on lumpy investment projects.

players select E, then both receive their high endowments in even periods. This is a simple device for modelling decisions to stagger or synchronize. These choices are made simultaneously and prior to the first period. To maintain symmetry between these choices, after the choices are made, Nature flips a fair coin to determine whether the first period will be even or odd. If the Nash equilibrium entails both players having high endowment in even or odd periods, then we term this a synchronized equilibrium. If the one player chooses high endowment in even (odd) periods and his opponent chooses to receive the high endowment in odd (even) periods, then a staggered equilibrium results.

Cooper and Haltiwanger [1992] shows that if $\pi_{12} > 0$, then agents will have an incentive to synchronize periods of high endowments. The intuition behind this result is straightforward. Strategic complementarities ($\pi_{12} > 0$) imply that each agent prefers to have a large value of their endowment when the other does as well: i.e. the marginal payoff from high endowment increases with the quantity given to the other agent.

Shleifer [1986] provides a rich example of the type of cyclical behavior that can be generated in a model with complementarity leading to synchronization. He considers a setting in which a subset of producers receive inventions every period. These producers have a choice of when to implement their inventions. The gain to implementation is that the firm enjoys a cost advantage over its rivals while the cost to immediate implementation is that other producers in the same sector can costlessly mimic the invention in the next period. Thus the firm has an incentive to introduce its invention when demand and thus profits are the highest. In a general equilibrium model with no capital, Shleifer shows that demand depends on aggregate profits creating a strategic complementarity in this economy across sectors. As a consequence, firms have an incentive to bunch the introductions of new products, creating endogenous implementation cycles.

Proposition II highlights the implications of strategic complementarity for the synchronization of discrete activities. There are certainly other forces which influence the timing of discrete decisions. A second force pushing in the direction of synchronization, see Bertola-Caballero [1990], is to assume that individual's respond to the random variables that influence their discrete choices and that aggregate uncertainty leads to synchronization. Clearly, the existence of common shocks will lead to synchronization even in the absence of strategic interactions. The key force that pushes against synchronization is the existence of idiosyncratic shocks which increase the gains to acting independently of other agents.

In the empirical section, we discuss evidence of synchronization. Here again, we point to examples in which synchronization is more likely to be the consequence of complementarity than the existence of aggregate shocks. While our emphasis is on the fact that some amount of temporal agglomeration is present in the data, we recognize that idiosyncratic shocks are empirically important given the degree of heterogeneity observed in the timing of discrete decisions.

D. Magnification and Propagation

The final proposition is a consequence of adding dynamics explicitly to the Cooper and John model. The consequence of doing so is that the existence of multiple static equilibria may imply multiple steady states and the complementarities may generate an endogenous source of persistence. In addition, the presence of complementarities may magnify shocks.

Proposition III: Magnification and Propagation: In the presence of complementarities, aggregate shocks will be magnified and propagated.

To see this point explicitly, return to the production externality model and suppose that there are no idiosyncratic shocks. Then, solving for the symmetric Nash equilibrium for levels of effort given (Y_{t-1}, θ_t) yields

$$\ln e_t = \frac{1}{2-\alpha}\{\ln\alpha + \epsilon\ln Y_t + \gamma\ln Y_{t-1} + \ln\theta_t\}. \tag{3}$$

In terms of equilibrium output,

$$\ln Y_t = \frac{1}{2-\alpha-2\epsilon}\{\alpha\ln\alpha + 2\gamma\ln Y_{t-1} + 2\ln\theta_t\}. \tag{4}$$

Expression (4) indicates that the amount of persistence in employment created endogenously by the model depends directly on the intertemporal spillover, γ. Further, the magnification of the shock to the technology, conditional on Y_{t-1}, depends directly on the magnitude of ϵ, the contemporaneous complementarity through the coefficient $2/(2-\alpha-2\epsilon)$. A shock to the economy influences output directly through the production function and indirectly through employment as given in (3). In turn, the shock influences employment directly and indirectly through the externality effect.

Baxter and King [1991] present a variant of the dynamic technological spillover model in a stochastic setting with capital accumulation. In their formulation, there are no lagged interactions between agents so that $\gamma=0$ is imposed. The emphasis of their work, summarized in further detail below, is on the role of complementarities in the magnification of shocks, including taste shocks meant to represent variations in demand. The magnification effects are indicated by the parameters that multiply the shock in the output equation. Clearly an increase in the contemporaneous complementarity (ϵ) will magnify shocks.

Durlauf [1991], in contrast, analyzes an explicit model of local complementarity in which there is general learning by doing. Thus that model incorporates lagged complementarities but, in contrast to Baxter and King [1991], excludes contemporaneous technological spillovers. The most important element of Durlauf's model is the assumption of local complementarity: the current productivity of agents in one sector is dependent upon the past activity level of other "nearby" sectors, not necessarily all of the sectors. Thus increases in productivity can begin in one sector of the economy and spread through the system due to the presence of local complementarities. In fact, as stressed in Durlauf [1991], the local complementarities create a much richer environment for the interaction of sectors.

There are other models that generate magnification and propagation in which the complementarities across sectors and time are not the consequence of production externalities but instead reflect final and factor demand linkages. As discussed earlier, the two-period analysis of Cooper and Haltiwanger [1990] created persistent aggregate effects from temporary sector specific shocks. The link across agents in that economy, as in the multi-sector models of imperfect competition by Hart [1982] and others, is that agents in one sector consume the goods produced by agents in other sectors. Of course, the strength of these effects depends on the extent to which current consumption responds to variations in current income. In contrast, factor demand linkages provide the basis for the propagation of shocks in the Long and Plosser [1983] model. In that economy, there are no strategic interactions. Dynamics are induced simply by the input/output structure of the economy.

III. Empirical Evidence

The point of this section is to provide an empirical evaluation of the main hypotheses of models with strategic complementarity. To do so, we draw upon a number of studies which fall into three categories. First, there are papers which estimate certain structural parameters that characterize strategic complementarities. Second, there are efforts to assess some of the implications of models of complementarities by searching for evidence of comovement, propagation and synchronization. Finally, there are papers which perform a quantitative comparison of models with complementarities to both alternative theoretical structures and observed moments in U.S. data. This section of the paper is organized around each of the three propositions outlined in the previous section and makes use of evidence from these three types of studies.

A. Positive Comovement

The fact that sectoral activity levels (measured by output or employment) tend to move together over the cycle is a well recognized element of aggregate fluctuations. As noted earlier, this positive comovement could either reflect the presence of some type of aggregate shock or the presence of strategic complementarities along with either sectoral shocks or an endogenous cycle. To determine the influence of complementarities on the observed positive comovement, we need to find ways to separate the common shock from the complementarity.

(i) *Basic Facts*

Empirical evidence on sectoral comovement is presented in Cooper and Haltiwanger [1990] for employment and Long and Plosser [1987] for output.[9] Looking at seasonally adjusted employment data at the 1-digit industry level, Cooper and Haltiwanger conclude that there is significant positive comovement in employment across sectors and that this does not appear to be the outcome of aggregate shocks. Rather, the results suggest the importance of sector specific shocks propagated through the system. Long and Plosser

[9] See also Hall [1991b] and Murphy, Shleifer and Vishny [1989] for further evidence on comovement.

[1987] reach similar conclusions in a study using output instead of employment, disaggregated by industrial production commodity groups.

Tables 1 to 3 summarize and extend these findings for commodity groups similar to those used in the Long and Plosser study. For each of 3 variables (output, employment, and prices), we report three types of correlations in their growth rates.[10] In Table 1, in the first column (NSA) is the average pairwise correlation across commodity groups for the output of each sector using seasonally unadjusted data. The second column (SA) computes the average correlation for seasonally adjusted data and thus represents business cycle frequency fluctuations. The third column computes the average pairwise correlation for the seasonal component of each series. These columns have the same interpretation for the tables using employment and prices.

There are a couple of points to see in these first three columns of Tables 1-3. For output, employment, and prices there is substantial positive comovement of the variables for the seasonally unadjusted series. The decomposition into the seasonally adjusted and seasonal components reveals that the positive comovement is especially pronounced at the seasonal frequency. The positive comovement in output, employment, and prices is certainly consistent with the comovement predicted by a model with strategic complementarity. It is inconsistent with the predictions of a real business cycle model with sector specific shocks as that model would yield negative correlations in employment as long as labor was sufficiently mobile to move from low to high productivity sectors. However, the evidence is consistent with a model in which there are aggregate shocks (either real or nominal) that generate positive comovement.

Given that the positive comovement is consistent with both complementarities and common shocks, additional tests are required to separate these effects. We consider a number of alternative strategies based upon the following moving average representation:

$$Y_t = A(L)\eta_t. \tag{5}$$

where Y_t is a vector of sectoral growth rates (of output, employment or prices) and η_t is a vector of innovations

[10] We investigate the correlations of growth rates as a means of rendering the series stationary.

to aggregate and sector specific shocks.[11] When we estimate a VAR on Y_t, we do not immediately recover either the estimates of A(L) or the vector of innovations to aggregate and sectoral disturbances. Instead, the VAR estimation yields (in its MA representation):

$$Y_t = D(L)\epsilon_t \ , \ D(0) = I. \tag{6}$$

where ϵ_t is a vector of reduced-form innovations (i.e.,the residuals from the estimated VAR). From this set of equations, we have $\epsilon_t = A(0)\eta_t$ and $A(L) = D(L)A(0)$ so that if we know A(0) we can recover both the innovations to the shocks and A(L) from the estimates of the VAR. The latter two expressions make clear the difficulty in distinguishing common shocks from contemporaneous complementarities. That is, large off-diagonal elements in the variance-covariance matrix of ϵ_t can reflect either large off-diagonal elements in the variance-covariance matrix of η_t or large off-diagonal elements in A(0).

In the fourth and fifth columns of Tables 1-3, we report the contemporaneous correlation of the reduced form innovations from estimating a six lag VAR on the growth rates of output, employment, and prices, respectively. Comparison of these columns with the first and the second columns provides a measure of how much of the observed comovement in the actual series is due to contemporaneous common shocks and/or the contemporaneous propagation of sectoral shocks. In Tables 1-3, this comovement is generally lower for the residuals of the series relative to the comovement in the actual series. This is particularly true for employment and prices and less so for output. Further, this relationship is stronger for the seasonally unadjusted data relative to the seasonally adjusted data.

These results indicate that an important fraction of the comovement is due to the contemporaneous effects of the innovations (rather than through propagation of lagged innovations). Hence, decomposing the variation in the innovations should be helpful in determining the sources of the comovement. There are a number of identifying assumptions that could be made in this context (i.e., assumptions about the structure of A(0)). First, one could assume that:

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[11] The lagged coefficients of A(L) capture both the serial correlation in the disturbances as well as dynamic propagation effects.

$$\epsilon_{it} = A_{\alpha i}\eta_{at} + \eta_{it} \tag{7}$$

where ϵ_{it} is the reduced form innovation for sector i in period t, η_{at} is an aggregate innovation, and η_{it} is a sector specific innovation for sector i in period t. In this case, it is assumed that only aggregate innovations and own sector specific innovations have contemporaneous effects while innovations from other sectors do not have contemporaneous effects (i.e., the coefficients in A(0) involving other sector shocks are set equal to zero). Thus, complementarities here only have a lagged effect in terms of propagating sectoral shocks but could have a multiplier effect for the contemporaneous common shock. Under this identifying assumption, common shocks are quite important in accounting for the comovement between sectors since they would represent the source of the relatively high contemporaneous correlations of innovations.

The assumption that sectoral linkages act only with a lag is a strong and arguably unacceptably strong identifying assumption. It limits the role of complementarities since contemporaneous propagation of sectoral shocks is ruled out. Rather than this strong identifying assumption, an alternative strategy is to to allow non-zero cross sectoral effects in A(0). The problem is this case is how to decompose the reduced form innovations into the aggregate and sectoral components. One means of doing so is to conduct a factor analysis of the innovations to determine the importance of common shocks in the innovation series. Both one and two common factor models are considered. The reported R^2's in Tables 1-3 indicate that common factors explain less than half of the innovations in the series for virtually all sectors with the seasonally adjusted data. For the seasonally unadjusted data, two common factors account for a larger fraction (e.g. as much as 70% of the variance of the innovations to output for the paper commodity group) but still a substantial portion of the variance of innovations is not explained by common factors.

The factor analysis suggests two conclusions. First, common shocks are more important at the seasonal frequency than the business cycle frequency. Second, the observed comovement at the business cycle frequency is not primarily due to the contemporaneous response of sectors to common shocks.

How should we interpret these results? They indicate that common contemporaneous shocks or contemporaneous propagation of sectoral shocks taken together account for an important fraction but certainly not all of the observed comovement. Put differently, dynamic propagation of common or sectoral shocks is important for the observed comovement.[12] Do these results help us to distinguish between the common shock and complementarity hypotheses? These results are interpretable as being supportive of the role of complementarities on the basis of the factor analysis. If, however, one makes the identifying assumption that the linkages across sectors occur with a one-period lag, then this yields a larger role for common shocks.

It is also instructive to compare these correlations against those reported in Cooper and Haltiwanger [1990]. In that study, the series were 1-digit industry groups for the entire economy and thus represented a broader spectrum of the economy than the more narrower industry groups underlying the results of Tables 1-3. Cooper and Haltiwanger find that for the broader industry classification, common shocks played a smaller role than they appear to under the narrower classification. This makes some sense in that technology shocks, at least, are more likely to be common to a group of agents involved in similar types of production activities. Put differently, this is evidence against the common shocks model.

Examination of price-quantity interactions between sectors sheds further light on the possible explanations of the observed comovement between sectors. Murphy, Shleifer and Vishny [1989] find that the relative prices of raw materials and intermediate inputs are significantly procyclical while the relative price of finished goods does not have a cyclical pattern. They use this evidence to argue that business cycle models which focus on the role of technology shocks upstream in the production process, thus producing countercyclical intermediate goods prices, are inconsistent with the evidence. Instead, the procyclical nature of the prices leads one to the view that correlated derived demand for inputs is responsible for the observed comovement in quantities and the procyclical behavior of upstream prices.

Direct examination of the price/quantity interactions using the more disaggregated sectors analyzed in Tables 1-3 reveals a wide variety of patterns. It is not difficult to find a pattern that provides support for the hypothesis that the comovement is driven by the spillover of technological shocks upstream to downstream sectors. For example, decreases in the growth rate of prices in the metals sector precede increases in the growth rate of output in both the metals sector and the transportation sector (the correlation between output

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[12] We do not explore the decomposition of the comovement into the contribution from aggregate and sectoral shocks via the dynamic propagation of shocks. This requires a set of assumptions to identify all of the elements of A(0).

growth in the metals sector and price growth in the metals sector lagged six months is -0.23 while the correlation between output growth in the transportation sector and price growth in the metals sector lagged six months is -0.17). In addition, there is substantial positive comovement in output growth rates between these two sectors (the contemporaneous correlation in growth rates is 0.41). Thus, in this case, it appears that price decreases in an upstream sector lead increases in quantities in both that sector and a closely linked downstream sector -- this is precisely the prediction of the technology shock, technological complementarities hypothesis and is in contrast to the evidence presented by Murphy, Shleifer, Vishny. A complete analysis of the dynamic cross-sectoral patterns of prices and quantities is beyond the scope of this paper. However, the evidence presented by Murphy, Shleifer and Vishny and that presented here suggests that this may prove to be a fruitful means of discriminating across alternative explanations of the observed comovement.

(ii) *Seasonality*

Further evidence of positive comovement is found in the empirical work on seasonal cycles. Barsky and Miron [1989] and Beaulieu and Miron [1990] find that seasonal fluctuations account for a large fraction of overall fluctuations and that seasonal cycles share many features with the business cycle. In contrast though, seasonal cycles seem much more deterministic and less likely to be the consequence of exogenous shocks to technology. Instead, taste shifts due to Christmas and July vacation periods seem to be important sources of variation over the year.

From the perspective of models of complementarities, the evidence on seasonal variations is insightful in a couple of ways. First, there is additional evidence of positive comovement across sectors of activity. Beaulieu and Miron [1990] look at 2-digit manufacturing over the 1967 to 1987 period using monthly observations and conclude that there is significant positive comovement across sectors over the seasonal cycle. For total manufacturing, the output growth rate in July is -13% and this is a month of negative growth for all of the 2-digit industries and the month of lowest growth in the year for most. In contrast, February is a high growth month overall, is high growth for all 2-digit industries and the month of highest growth for most. Similar results are reported by Long and Plosser and appear in column 3 of Tables 1 to 3.

Second, this comovement is unlikely to be a consequence of deterministic technological innovations over the seasonal cycle. Instead, taste variations for Christmas and summer vacations seem to be more important. As raised by Beaulieu and Miron [1990], the month of July is the common vacation period though from the perspective of the weather, August might be just as desirable. In other countries, notably France, August is the common vacation month. One source of this might be the presence of some form of complementarity that leads agents to wish to synchronize vacation periods, perhaps to allow for the retooling of machines. This is a point we return to in the section discussing empirical evidence on the synchronization of discrete events.

(iii) *Micro Evidence*

All of the discussion above is based upon evidence of sectoral comovement. Micro evidence on comovement (i.e., at the plant level) reveals considerable negative comovement within sectors. Davis and Haltiwanger [1990, 1992] present evidence of large simultaneous rates of job creation and destruction in every sector. Further, they find that the high observed rate of reallocation reflects primarily intrasectoral rather than intersectoral reallocation even at high levels of disaggregation. This evidence on large, negative comovement within sectors indicates that complementarities are not the dominant factor in accounting for microeconomic fluctuations. However, the macro models of complementarities under investigation here typically specify individual agents responding positively to some sectoral or aggregate measure of activity. Thus, the large negative comovement is not evidence against such sectoral or aggregate complementarities being present. Rather, the large negative comovement indicates that there are other factors that dominate at the micro level. First, as noted there may be large, idiosyncratic shocks. Second, within sector strategic interaction between agents is likely to reflect strategic substitutibility rather than strategic complementarity. Developing models that can accommodate both the within sector and the between sector evidence on comovement is an important area for future research.[13]

[13] The development of such a model is further complicated (in an interesting manner) by the finding by Davis and Haltiwanger [1992] that the idiosyncratic component of reallocation is significantly countercyclical. That is, the magnitude of the negative comovement within sectors increases in recessions. There is a growing literature of models attempting to account for this fact (see, e.g., Blanchard and Diamond [1990], Caballero and Hammour [1993], Mortensen and Pissarides [1993]). However, these models do not try to explain simultaneously the positive comovement between sectors, the negative comovement within sectors, and the countercyclicality of the negative comovement within sectors.

(iv) *What type of Complementarity?*

The strong evidence of between sector comovement is supportive of models with complementarities. Further, common shocks appear not to be able to fully account for this between sector comovement. An unresolved issue is what type of complementarities are responsible for this comovement. A recent paper by Shea [1993] directly addresses this question. Shea investigates three possible sources of the observed comovement: (i) factor demand linkages; (ii) an aggregate demand externality; (iii) geographically localized spillovers. His findings suggest strong support for the importance of input-output linkages but mixed support for the latter two types of complementarity.

(v) *Summary*

Overall, there is evidence in support of the positive comovement prediction found in models with complementarities. In particular, employment and output in different sectors tends to move together over both business and seasonal cycles. As noted numerous times, it is difficult to distinguish complementarities from common shocks as the basis of the comovement. Two pieces of evidence support the role of complementarities. First, the factor analysis points to the fact that common shocks are not the main source of comovement at business cycle frequency. Second, at the seasonal frequency, complementarities play a role in synchronizing activities over the seasons.

B. Synchronization

Proposition 2 concerned the timing of discrete choices by agents and noted that in the presence of strategic complementarity, agents had an incentive to synchronize. There are three issues here. First, are many important decisions at the micro level discrete? Second, are they synchronized? Third, what is the role of complementarities in accounting for any observed synchronization? The evidence in this section focuses on two related types of lumpy decisions: machine replacement and, more generally, investment in machinery and structures. For each we first discuss the nature of this discrete choice and then evidence on synchronization.

(i) *Machine Replacement*

Cooper and Haltiwanger [1993a] characterize a simple machine replacement problem (MRP) in which a producer decides whether or not to replace an existing piece of capital with a new one. In this example, the discrete choice is replace or not and the lumpiness is due to the discrete nature of the investment process. Thus, this approach is in contrast to models of convex adjustment costs in which changes to the capital stock are smoothed rather than bunched.

Evidence on discrete machine replacement is presented by Cooper and Haltiwanger [1993a] from an investigation of automobile producers. Using a variant of their machine replacement model, they document three important features of the annual model-year cycle for automobile producers. First, there is an annual shutdown in these plants, usually during the months of July and August, which is generally a time to retool, in terms of product and process innovations. This period of machine replacement is a key feature in the seasonal cycle for this and related (steel, rubber) industries. Second, these periods of retooling respond to the current state of the business cycle: retoolings generally lead to larger seasonal "recessions" during business cycle downturns. Third, the automobile producers appear to synchronize their shutdowns in the summer months. Thus this industry displays synchronized discrete choices.

(ii) *Investment*

Is there broader based evidence that machine replacement and more generally investment in machinery and structures are lumpy, synchronized decisions at business cycle frequencies? Ongoing studies by Doms and Dunne [1993] and Power [1993] using the LRD (Longitudinal Research Database -- establishment level data for the manufacturing sector) are beginning to shed light on these issues. For a sample of large, continuing plants over the 1972-88 period, Doms and Dunne find striking evidence of lumpy investment in machinery and structures. For their 16 year sample, plants concentrate 50% of their total cumulative 16 year investment in the three years with their largest investment. They note however that there is considerable heterogeneity in the importance of investment spikes across plants.[14] This may reflect differences in production and adjustment cost technologies. For our purposes, this heterogeneity indicates that the importance of the synchronization of discrete decisions may naturally vary across sectors.

What about the synchronization of the observed lumpy investment? Using data provided to us by Doms

[14] For example, they find that 45% of total investment by plants in their sample is associated with plants experiencing growth rates of capital less than 10%.

and Dunne, Figure 1 presents evidence indicating that this lumpy investment is synchronized and important for aggregate fluctuations in investment. In Figure 1, total investment for the manufacturing sector is plotted along with the frequency of plants experiencing their largest investment over the entire 16 year sample period. The strong positive relationship depicted indicates that changes in the frequency of investment spikes are important in accounting for fluctuations in aggregate investment. This suggests a new way of thinking about investment booms -- they may be driven more by changes on the extensive than on the intensive margin.[15]

(iii) *National Industrial Recovery Act*

The synchronization displayed in investment spikes using the LRD data as well as the synchronization of machine replacement by the automobile producers could emerge, as noted earlier, from the existence of complementarities across firms or due to the presence of common shocks (technological say for the investment spikes and value of leisure effects for the automobile shutdowns). One attempt to distinguish these two causes is presented in Cooper and Haltiwanger [1993b] study of retooling in the auto industry during the 1930s.

The National Industrial Recovery Act of 1933 was, in part, an attempt by the government to smooth seasonality in employment and output. Their attention was directed to the automobile industry due to the large seasonal fluctuations associated with the annual model changeover. From the mid-1920's through the early thirties, the annual changeover was synchronized to occur late in the calendar year, just prior to the automobile shows traditionally held in January. This meant that the two prime stimulants to automobile sales -- the effect of new models and good weather in the Spring -- coincided which lead to quite large fluctuations in sales, production and employment over the year. The costs of this in terms of limited production smoothing was appreciated by the producers but the costs of deviating to a smoother production plan (e.g. by introducing models say in July) were even higher, given that all other firms were retooling late in the calendar year. Cooper and Haltiwanger [1993b] describe this scenario in considerable detail and argue that the producers were caught in an inefficient equilibrium prior to 1935.

Starting in 1934 and culminating early in 1935, the National Recovery Administration, working with industry and labor leaders, agreed to an amendment to the industry code of conduct which called for producers

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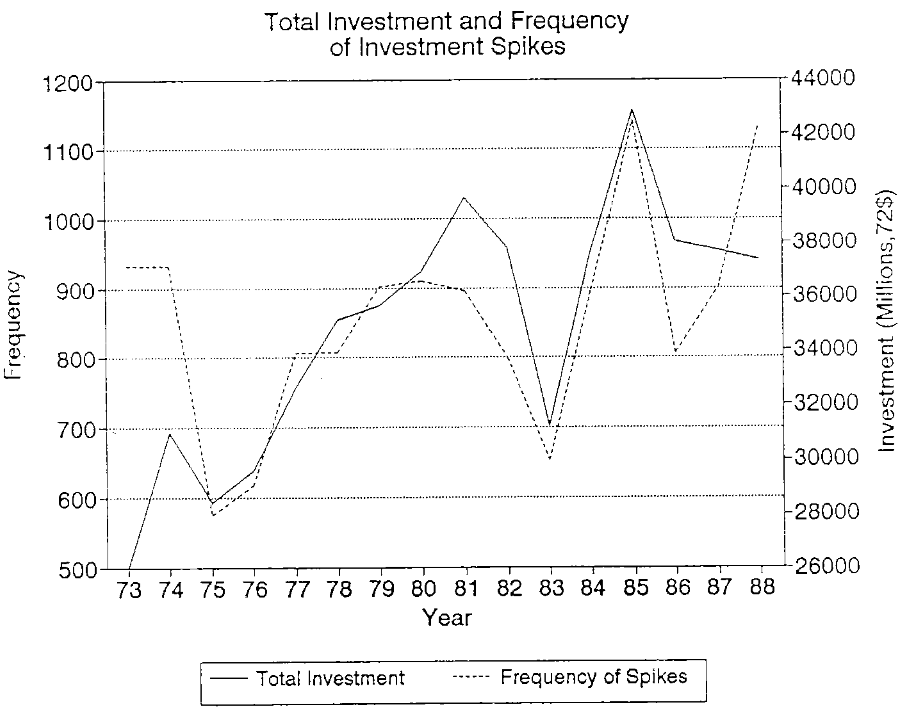
[15] The related study by Power [1993] also finds evidence that the probability of having an investment spike is cyclically sensitive.

Figure 1


Total Investment and Frequency
of Investment Spikes
1200
1100
1000
900
800
700
600
500
Frequency
44000
42000
40000
38000
36000
34000
32000
30000
28000
26000
Investment (Millions,72$)
73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88
Year
Total Investment
Frequency of Spikes

to alter, beginning in 1935, the timing of new model introductions. Starting in 1935, new models were to be introduced in October with the annual national automobile show starting shortly thereafter. Cooper and Haltiwanger document that a dramatic change in the seasonal pattern of production, employment and sales occurred beginning in 1935, apparently as an outcome of this agreement. This is made even more striking by the fact that in June 1935, the NIRA was ruled unconstitutional so that by the time the change in the pattern of new model introductions actually occurred, the NIRA was no longer in force.

Cooper and Haltiwanger argue that the agreement really provided a forum for "cheap talk" by the producers which lead them to focus on an alternative equilibrium with Fall model introductions which facilitated production smoothing over the model year. Further, Cooper and Haltiwanger argue that through a search of industry publications and through an investigation of residuals to production and sales regressions, that there were no apparent changes in fundamentals that might explain this sudden shift in automobile producer behavior. From this perspective, they argue that the observed synchronization reflected some form of complementarity, modeled formally as a marketing externality through the annual automobile show.

(iv) *Summary*

The evidence generated here points to two facts. First, there are numerous examples of discrete actions which are temporally agglomerated. Second, there is at least one case, the change in the timing of model years, in which we can argue that complementarities were responsible for the temporal agglomeration. Distinguishing common shocks and complementarities in generating temporal agglomeration in other cases remains an open issue.

C. Magnification and Propagation

The third theoretical proposition concerned magnification, due to intratemporal complementarity, and propagation, due to intertemporal complementarity, of exogenous shocks. Recent work on this theme has stressed one form of complementarity based on Bryant [1983] in which the productivity of one agent is influenced by the activity of others as in the production externality model given above. To turn this into a working model of the aggregate economy requires two steps. One is the estimation of the key parameters and the other is to imbed this interaction into a dynamic economy with capital accumulation.

(i) *Basic Models*

Baxter and King [1991] is one leading attempt in this direction. In their model, all intertemporal linkages are omitted (i.e. $\gamma=0$ in the model above). The production function for an individual agent is thus given by

$$y_t^i = A_t(n_t^i)^\alpha(k_t^i)^{(1-\alpha)}Y_t^\epsilon \tag{8}$$

where variables with an "i" superscript again refer to the choices of agent i and Y_t is the average level of output in period t. Note that this technology includes capital as well as labor in a Cobb-Douglas form imposing constant returns to scale.

In their economy there are a number of private agents who maximize the discounted present value of utility subject to this production function. In the Baxter and King formulation, agents are subject to two sources of uncertainty: production and taste shocks. The latter source of uncertainty provides a basis for "demand disturbances" in that the shock does not immediately impact the production process. In each period agents decide on a level of employment and a level of investment in the single capital good.

Formally, the Baxter and King economy represents a dynamic game. However, the analysis is greatly simplified by the fact that all agents are identical so that in equilibrium they make identical choices. Thus the equilibrium path of the economy can be analyzed through a system of equations that is quite similar to the system analyzed by King,Plosser and Rebello [1988] though in the Baxter and King formulation there are social returns to scale.

Based on the arguments advanced by Durlauf [1991] and others, it is reasonable to consider a model with dynamic externalities that might represent some generalized version of a learning by doing model. Alternatively one could imagine amending models of demand linkages to create a lag between the payment to workers and firm owners and the demands generated by those flows. For these models, the technology for an individual producer would be given by

$$y_t^i = A_t(n_t^i)^\alpha(k_t^i)^{(1-\alpha)}Y_{t-1}^\gamma. \tag{9}$$

(ii) *Estimation of Technological Spillovers*

A critical point in evaluating these models is the magnitude of the production externality parameters. In particular, identifying complementarities from common technology shocks is often quite difficult. Baxter and King first estimate ϵ through an OLS regression of output growth on weighted input growth. This yields an estimate of ϵ of about .31 but this is biased if there is a technology shock that is correlated with employment. To overcome this, they consider instruments advocated by Hall [1988] (military spending measures) as well as other measures (defense compensation and total nondefense purchases) and obtain estimates that range from .1 to .45 depending on the instrument.[16]

Caballero and Lyons [1992] and Bartlesman,Caballero and Lyons [1991] estimate technological spillovers using disaggregated data. Caballero and Lyons investigate technological spillovers between 2-digit industries and aggregate output. Looking at the U.S., their point estimate of the contemporaneous spillover is about .32 assuming that there is no labor hoarding.[17] More importantly, Caballero and Lyons argue that the presence of a technological externality implies that estimates of returns to scale should be higher using aggregate data than using 2-digit observations.[18] In contrast, other sources of procyclical productivity, such as labor hoarding, will not produce differences in estimated returns to scale. Their evidence that the estimates of returns to scale are higher at the aggregate level suggests the presence of technological spillovers.

Bartlesman, Caballero and Lyons provide additional evidence on the nature of these linkages by studying U.S. manufacturing at the 4-digit level and paying particular attention to the nature of linkages across producers. They find that over short periods of time, "demand" externalities are relatively important but that over longer time periods, linkages through suppliers appears more important. Their estimates of the externalities operating at business cycle frequency fall into the same range as reported by Baxter and King [1991] and Caballero and Lyons [1992].

[16] It is noteworthy that all of the instruments had rather low first stage explanatory power. This point is made by Shea [1993a] as well in his investigation of 2-digit output variations.

[17] This comes from their Table 2 assuming that $\mu=0$.

[18] To see this, consider a simple production relation (in logs) for sector i where $y_t^i = \alpha n_t^i + \epsilon Y_t + \xi_t^i$ implying that in aggregate terms, $Y_t = (\alpha/(1-\epsilon))n_t + \xi_t$.

An alternative approach to estimating these technological spillovers is to return to the evidence discussed earlier on seasonal productivity fluctuations. The assumption that seasonality is not the consequence of common technology shocks allows one to identify the influence of technological spillovers. To see this formally, one can directly modify the production externality model by introducing deterministic seasonal variation in the marginal rate of substitution between consumption and leisure. This is an important alternative to the studies mentioned thus far the focus on seasonality provides a natural means of distinguishing complementarities from common shocks.

A leading example of this is found in Braun and Evans [1991]. They estimate a seasonal model in which both labor hoarding and technological spillovers are present. It is quite interesting to note that their estimate of the contemporaneous technological spillover is quite close to that reported by Baxter and King. Further, Braun and Evans argue that both labor hoarding and technological spillovers must be present to match observed seasonal movements.

Table 4 reports estimates of technological spillovers using the same data as analyzed by Beaulieu and Miron. By sector, we first estimated the production relation between output (measured as shipments plus inventory change, what Miron and Zeldes [1989] denote as the Y4 measure) and labor input (total production worker hours) using monthly data for the period 1967:1 to 1988:4.[19] Table 4 indicates that the elasticity of output with respect to the labor input is quite high for most sectors. Table 9 of Beaulieu and Miron [1990] decomposes this elasticity into a seasonal and a non-seasonal component and finds that for 14 of the 20 2-digit manufacturing sectors, the seasonal elasticity exceeds one. Further, this elasticity is generally higher for seasonal than for business cycle variations.

The next two sets of regression results in Table 4 attempt to interpret the evidence on short run returns from the perspective of a complementarities model using seasonal variation as a means of eliminating the influence of exogenous technological shocks. This is accomplished by using seasonal dummies as instruments in

[19] Note that the time period and the output measures are different than those used to compute the comovements in Tables 1-3. For Table 4 we chose to use the Beaulieu-Miron results as a benchmark and so adopted their choice of time period and measurements. The Y4 output measure is perhaps more appropriate for an analysis of labor productivity since the industrial production measure (an alternative measure of output) is computed using labor input data for a significant fraction of the industries.

estimating the relationship between sectoral output, sectoral inputs, and a measure of aggregate activity. We interpret the coefficient on the measure of aggregate activity as reflecting the influence of production related externalities (i.e., an estimate of ϵ in the production externality model of section II.A)

For these regressions, total manufacturing output was used as the measure of aggregate activity. For the first IV estimates, the labor input measure was total hours. In general we see that the coefficient on the labor input, relative to the OLS estimate, is lower and that the coefficient on aggregate output is positive and significant. In fact, the production externality parameter estimates are strikingly large. There are a number of concerns that may be biasing these estimates. While we might argue that exogenous technological change is not operative at the seasonal frequency, there is certainly the possibility of unmeasured variation in inputs at the seasonal frequency. Although capital presumably does not vary seasonally, capital utilization, intensity of labor effort and material inputs presumably do vary seasonally. Braun and Evans deal with some aspects of this problem in their related estimation using quarterly data -- in particular they explicitly model intensity of labor effort and attempt to take this into account in their estimation.

Here we attempt to assess empirically how important these measurement problems might be by introducing additional "measurement error" and supposing that only the number of employees is observable. The results from using this as a measure of labor input are reported in the last two columns. Note that, as expected, the omission of hours, raises the coefficient estimate on the employment measure since hours variations are now influencing the error term. However, the coefficient estimates on the production externality remain relatively unchanged. From this we argue that other components of employment variation (both unobserved effort and measurement problems associated with shutdowns) or other unobserved inputs might lead to a biased coefficient on the labor input but may yield only small biases in the estimate of the externality parameter. This said, we are still unable to explain the magnitude of our estimates relative to those found in other studies. In any event, these strikingly large estimated production externality effects are difficult to ignore -- they clearly motivate further investigation. Overall, we see support for significant technological complementarities in a wide variety of empirical studies.

For the model in which the complementarities are dynamic, Cooper and Johri [1993] consider a model in which the contemporaneous spillovers are replaced by lagged complementarities: i.e. $\epsilon=0$ but γ may not be zero. The OLS estimate of the parameter γ is .15 using annual data from 1947 to 1986.[20]

(iii) *Quantitative Aggregate Implications*

Based on these parameter estimates, one can integrate a production technology which allows for contemporaneous and lagged spillovers into an otherwise standard real business cycle framework. In this setting, an individual optimizes the discounted present value of utility flow where utility in a period depends on the consumption of goods and leisure. Individuals accumulate capital through a standard investment process. In making their decisions, individuals take the aggregate variables as given. In equilibrium, agents all choose the same actions since they are identical. The quantitative implications of the models are then obtained from a log-linear approximation around the steady state of such an economy.[21]

The results from a variety of quantitative experiments with both contemporaneous and lagged technological externalities are summarized in Tables 5 to 7. For each, there are three treatments. A baseline in which there are no externalities $\epsilon=\gamma=0$ which corresponds to the standard real business cycle model. The second treatment follows Baxter and King in which there are only contemporaneous spillovers set at their estimate of $\epsilon=.23$. The final treatment incorporates lagged but no contemporaneous spillovers with $\gamma=.15$.

There are two points to emphasize from these tables. The first concerns the quantitative properties of models with technological spillovers and serially correlated technology shocks relative to the baseline model and to quarterly U.S. data. Table 5 provides the basis for these comparisons. Both of the models with externalities do quite well in reproducing the basic features of business cycles, including the volatilities of consumption and investment relative to output and the requisite persistence in the series. By this measure, models with externalities appear to do no worse than the standard real business cycle model.

The contribution of these externalities in magnifying and propagating shocks is illustrated in Tables 6

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[20] This estimate is obtained by regressing the Solow residual (constructed as the difference between output and weighted input growth with a weight of .54 on labor) on lagged real GNP growth. This procedure reproduces the Baxter and King estimates of contemporaneous technological spillovers. Note that as long as technology shocks are not serially correlated, there is no bias in the estimate of the lagged technological spillover induced by the response of agents to variations in the state of technology.

[21] Unless otherwise noted, we discuss properties of an economy in the neighborhood of a steady state which is saddlepath stable.

and 7. For Table 6, the technology shock is restricted to be temporary to highlight the endogenous propagation of the model. As is well understood, there is little endogenous propagation in the baseline model: the serial correlation of output is only .026. Introducing contemporaneous spillovers substantially increases the standard deviation of output and creates some additional serial correlation in output.[22] In contrast, the presence of a lagged complementarity creates little extra volatility but the amount of serial correlation in output is now .30. Thus, dynamic complementarities can generate a quantitatively significant amount of serial correlation in output.

In Table 7, the impact of a serially correlated shock to tastes is introduced. As in Baxter and King, the taste shock creates variation in the marginal rate of substitution between consumption and leisure. Baxter and King find that a model with external increasing returns and serially correlated taste shocks reproduces key features of the business cycle such as positive comovement of consumption and investment with output with consumption less volatile and investment more volatile than output. The key issue here is the positive correlation between investment and output. Temporary taste shocks lead to negative correlation between investment and output since the urgency to consume today leads to an increase in production and a reduction in investment. Relatively permanent taste shocks increase labor supply for long periods of time rationalizing an accumulation of capital. If this effect dominates, then the models can produce a positive correlation between investment and output.

This is seen in Table 7. Here the serial correlation in the taste shock is set at .95, close to the .97 estimated by Baxter and King. Note that in the model without any social returns to scale, taste shocks lead to a negative correlation between output and investment. This correlation is positive once contemporaneous spillovers are introduced. The model does not produce procyclical productivity despite the external returns to scale though the correlation between productivity and output is higher in the presence of social returns. Nor is the standard deviation of investment greater than that of output and consumption.[23] A final word of caution is in order here. These results are quite sensitive to the assumed serial correlation in the taste shocks. Reducing

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[22] From their Table 4, Baxter and King find that the introduction of the externality increases the variance of output by about 75%.

[23] In Baxter and King [1991, Table 4], investment is more volatile than output and consumption. The difference is apparently due to their filtering of the data.

the serial correlation to .9 leads to a negative correlation between investment and output in all models and increasing the serial correlation to .97 leads to positive correlation in all models.

From the perspective of evaluating models with complementarities, these results are insightful in two ways. First, they point to the fact that models with technological complementarities are not obviously at variance with U.S. data. The presence of the production externality is confirmed by the estimation and the statistical properties of the model with this added feature improve the fit with U.S. data. Second, the fact that the model reproduces some basic features of the business cycle when driven by "taste shocks" points to the ability of models with complementarities to accommodate demand side disturbances. Thus, there is the possibility of combining complementarities with more interesting sources of fluctuations, such as monetary disturbances as in recent work by Beaudry and Devereux [1993].

One issue not completely addressed in this discussion is the nature of the dynamics in models with complementarities. Benhabib and Farmer [1992] point out that in many models with externalities and/or monopolistic competition, as in the Baxter and King model, the local dynamics may be fundamentally different. In this regard, for the simulations reported by Baxter and King and those reported above, the steady state equilibrium was saddlepath stable. As noted by Benhabib and Farmer, high values of the contemporaneous production externality (or sufficiently large markups) coupled with highly elastic labor supply, can fundamentally change the local dynamics around the steady state and a sink may emerge. In this case, given an initial stock of capital different from the steady state level, there will be multiple paths all converging to the same steady state.

Quantitative analyses have been performed in models where complementarities arise in ways not captured by the production externalities model. Farmer and Guo [1993] use the observations of Benhabib and Farmer [1992] to generate sunspot behavior around the steady state of an economy with monopolistic competition and argue that their model reproduces basic features of the business cycle where the driving process is not related to fundamental changes in either tastes or technology. Chatterjee and Cooper [1993] analyze a model of monopolistic competition with entry and exit. In this analysis, there is a "love of variety" that provides a complementarity that substitutes for a direct production externality. Chatterjee and Cooper find that entry and exit interacting with variations in product variety provide a powerful source for the magnification and propagation of technology and taste shocks. For both of these models, the specification allows one to identify the parameter determining the complementarity from markups and thus overcomes the problem of identification of a technological spillover parameter.

(iv) *Summary*

Overall, there is evidence from a variety of studies indicating the presence of complementarities in the form of the production externality model. Building on this, we have shown how these interactions can be integrated into a dynamic, stochastic model of the macroeconomy without violating the standard observations on aggregate fluctuations. The results of Baxter and King [1991] and Beaudry and Devereux [1993] suggest that further work on combining demand variations with complementarities may be a useful way to proceed.

D. Non-linear Time Series

A final topic we consider is evidence on the non-linear nature of time series and its relation to models with strategic complementarity. One study that has received considerable attention is that of Hamilton [1989] who considers a Markov structure in which the economy can shift between high and low growth regimes. Estimating this model on U.S. time series, Hamilton finds evidence of regime shifts.

This evidence is complemented by a recent study by Cooper and Durlauf [1993] who investigate non-linearities in aggregate time series using regression tree analysis. This is a methodology for searching for break in a series that may correspond to nonlinearities in a wide variety of dimensions. Cooper and Durlauf apply these techniques to a study of Industrial Production from 1923 to 1991. In principle, breaks in the data can be indexed by time, output levels and other important variables. The methodology, described in some detail in their paper and the references therein, chooses the optimal number and nature of the breaks. They can reject the hypothesis that the entire sample could be represented by a single AR(2) process. Instead, they find evidence for breaks in the data both based on time and detrended output.

How does this evidence of non-linearities in these studies relate to models with complementarities? Economies with complementarities can easily exhibit non-linear behavior associated with shifts across regimes. The multiple regimes, in turn, reflect the multiplicity of equilibria. To see this consider a static model, as in

Cooper and John, in which the strategic complementarity is sufficient to generate multiple equilibria. For given parameters of the game (θ), let the set of equilibria be given by $\xi(\theta)$. For some values of θ there may be multiple equilibria and for others there may be unique equilibria of the stage game. Now, suppose that this game was repeated a number of times with a new value of θ drawn in each period with an equilibrium chosen out of the set $\xi(\theta)$. For some realizations of θ there will be multiple equilibria of the stage game and thus some other mechanism must be used to select an equilibrium. Over time, as different values of the shocks are realized the set of equilibria can change quite dramatically possibly leading to regime shifts.

Cooper [1993] advocates the use of a history dependent selection device in which the outcome in period t, assuming there are multiple equilibria in the period t stage game, depends upon which branch of the equilibrium correspondence the economy was in the previous period. In that model, the multiple equilibria stem from a choice of technique by firms (e.g. the number of shifts) that generates procyclical productivity as well as non-linearities associated with regime shifts.

An alternative approach advanced by Weil [1989] uses "sunspots" to select an equilibrium outcome. Here the economy would fluctuate across equilibria depending upon the outcome of some commonly observed variable that is a source of extrinsic uncertainty. This is a way, following Azariadis [1981], to model the notion that beliefs themselves can influence aggregate activity in a self-fulfilling way. The work of Guo and Farmer [1993], described above, is another attempt in this direction.

IV. Conclusions

Our goal in this paper was to assess the empirical implications of an economy with some form of strategic complementarity. The brief theoretical section was intended to give the reader some background in this literature and to provide a statement of propositions that have emerged from a wide variety of studies.

Our empirical evidence provides support for models of complementarities by indicating that these models are not inconsistent with basic features of aggregate data. A weakness in our approach is that in many such instances there are competing models without complementarities that are also consistent with the same set of facts. In response, we have attempted to stress studies in which complementarities provide novel insights (the study of the NIRA by Cooper and Haltiwanger [1993b]) and results which isolate the importance of complementarities as distinct from, say, common technology shocks (such as the Braun and Evans estimates of technological complementarity using seasonal observations).

Using a horse race analogy, one might argue that this discussion has focused more on pointing out that models with complementarities represent a horse that is deserving of consideration. While there has been some progress in determining the outcome of the race, much work remains. To us this research line is critical since, from the perspective of the welfare of individual agents in the economy, models with complementarities provide an internally consistent, optimizing framework in which there really are economic opportunities that are not realized due to the inability of agents to coordinate decisions.

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Table 1: Analysis of Comovement of Output[1]									
	Average Pairwise Correlations[2]					Factor Analysis of Innovations[3]			
Sector	NSA	SA	SEAS	Inn.N SA	Inn. SA	R^2 1F NSA	R^2 2F NSA	R^2 1F SA	R^2 2F SA
Foods	.60	.28	.70	.47	.28	.48	.48	.32	.34
Textiles	.64	.27	.76	.52	.27	.61	.68	.32	.40
Leather	.56	.10	.67	.42	.11	.41	.52	.05	.16
Fuels,Power	.09	.07	.11	.13	.03	.03	.08	*	.04
Chemicals	.53	.28	.65	.42	.24	.39	.61	.26	.47
Rubber	.64	.30	.74	.52	.29	.60	.63	.35	.37
Lumber	.62	.22	.77	.45	.28	.45	.45	.30	.30
Paper	.65	.34	.74	.55	.33	.69	.70	.48	.52
Metals	.58	.33	.70	.51	.31	.57	.57	.37	.37
Machinery	.55	.29	.69	.45	.28	.44	.44	.29	.36
Furniture	.64	.32	.74	.53	.32	.63	.64	.44	.44
Mineral	.57	.25	.69	.48	.27	.49	.54	.27	.35
Transport.	.43	.20	.54	.41	.20	.36	.36	.16	.17
Misc.	.65	.29	.75	.55	.30	.68	.68	.39	.40

[1] Output growth rates calculated from monthly industrial production indices for commodity groups from 1969:1-1992:3

[2] Average pairwise correlations of innovations based upon VAR specification with six lags.

[3] Reported R^2 are fractions of VAR residual variance explained by common factors (1F refers to one factor model, 2F to two factor model).

* Less than .005

Table 2: Analysis of Comovement of Employment[1]

	Average Pairwise Correlations[2]					Factor Analysis of Innovations[3]			
	NSA	SA	SEAS	Inn. NSA	Inn. SA	R^2 1F NSA	R^2 2F NSA	R^2 1F SA	R^2 2F SA
Foods	.31	.20	.39	.23	.16	.19	.25	.16	.24
Textiles	.48	.43	.57	.46	.30	.77	.79	.48	.51
Leather	.40	.20	.54	.31	.05	.36	.39	.01	.04
Fuels,Power	.10	-.04	.32	-.03	-.02	*	*	*	.02
Chemicals	.40	.37	.45	.34	.16	.37	.38	.12	.12
Rubber	.43	.36	.61	.29	.17	.28	.28	.15	.15
Lumber	.42	.35	.51	.31	.21	.36	.40	.30	.39
Paper	.46	.43	.52	.39	.26	.51	.51	.38	.38
Metals	.49	.45	.61	.40	.28	.57	.77	.46	.67
Machinery	.26	.31	.30	.15	.11	.06	.08	.06	.07
Furniture	.50	.46	.59	.36	.24	.44	.44	.32	.33
Mineral	.46	.44	.51	.34	.22	.41	.41	.28	.28
Transport.	.26	.24	.35	.21	.17	.17	.54	.21	.52
Misc.	.53	.42	.63	.39	.23	.52	.54	.32	.36

[1] Employment growth rates calculated from monthly total employment by industry commodity groups from 1969:1-1992:3 (concordance with SIC used).
[2] Average pairwise correlations of innovations based upon VAR specification with six lags.
[3] Reported R^2 are fractions of VAR residual variance explained by common factors (1F refers to one factor model, 2F to two factor model).

* Less than .005

Table 3: Analysis of Comovement of Prices

	Average Pairwise Correlations[2]					Factor Analysis of Innovations[3]			
Sector	NSA	SA	SEAS	Inn. NSA	Inn. SA	R^2 1F NSA	R^2 2F NSA	R^2 1F SA	R^2 2F SA
Foods	.20	.11	.70	.08	.06	.06	.07	.05	.06
Textiles	.41	.21	.83	.07	.05	.05	.06	.03	.04
Leather	.21	.02	.73	.04	*	.03	.05	.01	.04
Fuels,Power	.27	.22	.71	.06	.05	.04	.04	.04	.05
Chemicals	.48	.37	.84	.14	.11	.18	.39	.14	.36
Rubber	.49	.38	.81	.13	.08	.13	.16	.07	.11
Lumber	.11	-.03	.50	.07	.06	.05	.07	.04	.04
Paper	.52	.36	.84	.16	.11	.21	.40	.13	.33
Metals	.50	.38	.83	.22	.18	.41	.43	.36	.37
Machinery	.54	.39	.84	.18	.17	.24	.28	.24	.28
Furniture	.52	.36	.83	.19	.17	.35	.46	.36	.45
Mineral	.49	.33	.81	.14	.10	.19	.30	.14	.29
Transport.	.22	.16	.32	.02	.02	*	.06	*	.02
Misc.	.35	.20	.76	.11	.11	.15	.26	.18	.25

1 Price growth rates calculated from monthly producer price indices by industry commodity groups from 1969:1-1992:3.

2 Average pairwise correlations of innovations based upon VAR specification with six lags.

3 Reported R^2 are fractions of VAR residual variance explained by common factors (1F refers to one factor model, 2F to two factor model).

* Less than .005

Table 4: Externality Estimates using Seasonal Instruments[1]

Sector	OLS	Seasonal IV		Seasonal IV	
	Total Hours	Total Hours	Total Manu.	Employment	Total Manu.
total Manu.	1.39*	1.71*	—	4.15*	—
durables	1.61*	.20*	1.2*	.39*	1.19*
nondurables	1.07*	.19*	.7*	.62*	.64*
food (20)	.54*	.44*	.60*	.54*	.58*
tobacco (21)	.67*	.27*	1.41*	.29	1.49*
textiles (22)	1.72*	1.06*	1.42*	3.20*	1.23*
apparel (23)	1.24*	-.64**	1.62*	-.4	1.48*
lumber (24)	1.08*	.70*	.83*	1.20*	.87*
furn. (25)	1.19*	.09	1.33*	2.02*	1.03*
paper (26)	.26	-.83*	.85*	-.29	.81*
printing (27)	.26	.07	.52*	.62	.51*
chemical (28)	1.73*	.20	.75*	-.52	.78*
petro. (29)	.11*	.44*	.1**	.57*	.1
rubber (30)	.98*	-.46**	1.27*	.46	1.08*
leather (31)	.86*	.40	.80*	1.04*	.58*
stone (32)	.78*	.46*	.81*	.87*	.82*
prim. met. (33)	1.37*	-.01	.85*	1.19*	.76*
fab. met. (34)	1.43*	-.10	1.3*	-.63	1.38*
machine (35)	2.54*	2.8*	.93*	5.5*	.91*
elec. mach. (36)	1.98*	1.18*	1.26*	1.79*	1.29*
trans. (37)	.89*	.36*	1.33*	.9*	1.25*
instrum. (38)	2.35*	1.15*	1.17*	3.74*	1.1*
other (39)	1.58*	.42**	1.27*	.72*	1.20*

[1] This is the data set used in Beaulieu-Miron. The data are monthly and are not seasonally adjusted. For the seasonal IVs, the instruments were seasonal dummies for the months. For the hours column the labor measure was total production worker hours and for the emp. column the labor measure was total number of workers. The output measure was Y4.

*--Significant at the .01 level

**--Significant at the .05 level

Table 5
IID Technology Shocks

TREATMENT	Corr. with Y Contemporaneous				Standard Deviation Relative to Y				Statistics for Y	
	C	Hrs	Inv	Prod	C	Hrs	Inv	Prod	sd	serial corr.
$\gamma=0,\epsilon=0$	.36	.98	.99	.87	.19	.76	3.4	.29	.013	.026
$\gamma=0,\ \epsilon=.23$	.37	.97	.99	.85	.22	.75	3.4	.31	.023	.046
$\gamma=.15,\epsilon=0$	.42	.96	.98	.83	.26	.74	3.3	.35	.014	.30

Table 6
Serially Correlated Technology Shocks*

TREATMENT	Corr. with Y Contemporaneous				Standard Deviation Relative to Y				Statistics for Y	
	C	Hrs	Inv	Prod	C	Hrs	Inv	Prod	sd	serial corr.
$\gamma=0,\epsilon=0$	.80	.80	.92	.89	.62	.50	2.46	.67	.032	.924
$\gamma=0,\ \epsilon=.23$	.84	.76	.91	.91	.68	.46	2.3	.72	.055	.938
$\gamma=.15,\epsilon=0$	.83	.77	.91	.91	.66	.46	2.3	.71	.042	.96
U.S. Data	.85	.07	.6	.76	.69	.52	1.35	1.14	.056	.96

* Here the serial correlation in the technology shock is .9 for the three treatments.

Table 7
Serially Correlated Taste Shocks*

TREATMENT	Corr. with Y Contemporaneous				Standard Deviation Relative to Y				Statistics for Y	
	C	Hrs	Inv	Prod	C	Hrs	Inv	Prod	sd	serial corr.
$\gamma=0,\epsilon=0$	.99	.98	-.99	-.94	1.89	2.01	1.29	1.04	.0092	.94
$\gamma=0,\ \epsilon=.23$	1.0	.99	.99	-.99	1.35	1.3	.11	.3	.016	.95
$\gamma=.15,\epsilon=0$	.99	.99	-.75	-.99	1.56	1.58	.55	.58	.012	.97

* Here the serial correlation in the taste shock is .95 for the three treatments.