STRATEGIC BEHAVIOR, REAL RIGIDITIES, AND PRODUCTION COORDINATION FAILURES

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INTRODUCTION

Two prominent but essentially separate strands of the New Keynesian literature are wage/price rigidity models and coordination models.[1] Wage and price rigidity models attempt to explain inflexible wages and prices (either real or nominal) as a result of optimization by economic agents and/or the interaction of agents in a market. This rigidity may result in sub-optimal economic performance. Popular examples include mark-up, implicit contracts, insider-outsider, menu costs, and efficiency wage models [Fischer, 1988, 315-32; Gordon, 1990; Romer, 1993]. In contrast, coordination-failure models generate results with inferior welfare properties because economic agents lack the incentives to change their behavior to reach a more preferred welfare state [Cooper and John, 1988; Van Huyck, Battalio and Beil, 1990; Bryant, 1993].

Because most coordination-failure models do not explicitly analyze the exchange process [van Ees and Garretsen, 1992, 471] and the development of the wage/price rigidity and coordination strands of the New Keynesian literature have been separate and sometimes competitive [Ball and Romer, 1991], a systematic presentation of the role of prices, specifically rigid versus flexible prices, within the context of coordination models is not well established.[2]

However, a role has been proposed. For example, Colander states, "[C]oordination failures mean that even with wage and price flexibility an economy can arrive at an equilibrium with lower output than could be arrived at with alternative institutional coordination mechanisms. [L]imiting wage and price flexibility might be able to improve on that equilibrium" [1992, 445]. Van Ees and Garretsen state, "New Keynesian economics is a serious attempt . . . to show that coordination failures are inherent to the functioning of a decentralized economy, even if prices are flexible (or sometimes because prices are flexible)" [1992, 465].

As is the case in the general New Keynesian literature, it is not always clear whether the price rigidity associated with coordination models is nominal or real.

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Recent work on coordination models has focused on nominal-price rigidity; however, the results are conflicting. Ball and Romer [1991], using a model that mixes menu costs with price coordination, show that nominal-price rigidity is associated with price-coordination failure and Pareto-inferior results. In contrast, Mischel [1998], using a model in which firms adjust price in response to a demand shock, and Bohn and Gorton [1993], using a demand externality model with money and nominal contracts, suggest that sticky nominal prices produce an equilibrium that is Pareto-preferred to that produced by flexible prices.

These contributions, however, have not addressed the relationship of real-price rigidity to coordination failure for one of a broad class of coordination models called the production-coordination model. This paper presents a production-coordination model in an explicit pricing context. This coordination model will then be used to examine how the incorporation of fixed and flexible real-price systems alters the operation of the model, specifically how the price regime impacts strategic behavior of suppliers and thus the level of production in the economy.

The following section begins with an overview of the development and importance of coordination failures and introduces the production-coordination model. We then develop and analyze a production-coordination model incorporating complementarities among intermediate-input and final-good producers.[3] Although money could play an accounting and transactions role without substantively changing the results, production-coordination models are essentially real-exchange models. Therefore, the model is presented in real terms. Constraints on the degree of communication between intermediate-input suppliers and between final-good and intermediate-input suppliers may result in a sub-optimal level of production [Bryant, 1993].

This paper's model differs from Bryant's [1983; 1993] by having an explicit final-good production sector. In addition, this paper's model substitutes marketing trading and price setting firms for Bryant's assumed allocation system. Initially, Bryant uses a Walrasian price mechanism to show that the resulting Nash equilibrium will be zero output. This pathological result persuaded Bryant to substitute an equal-sharing feature to guarantee a nonzero Nash equilibrium. Using Bryant's institutionally-determined allocation system in this paper's model results in similar conclusions. Therefore, we connect the model to the existing literature and its conclusions when a pricing system is not employed. However, the following sections of the paper replace the institutional allocation system with an explicit trading/pricing system and develop the behavior and results under this market system.

We continue by presenting the trading mechanism and developing the behavior of the final-good and intermediate-input suppliers in a pricing system. This provides the basis for the first three propositions. Proposition 1 states that a flexible, real-price system fails to improve the welfare properties of the economy and can actually cause welfare to deteriorate by introducing serious production instabilities. In contrast, Proposition 2 states that downwardly inflexible prices as a response to demand constraints may result in sustainable, Pareto-preferred outcomes. Although both the context and application are different, the advantage of inflexible prices in stabilizing output in this production-coordination model complements a strand of the New Keynesian literature that proposes that inflexibility of wages and prices will reduce economic fluctuations [Greenwald and Stiglitz, 1993, 25].

Colander [1992] suggests that perfectly flexible prices will generate such instability that institutions will be created to substitute a rigid-price system. The model presented in this paper, however, indicates that formal institutions to limit price movements may not be necessary. Proposition 3 states that price rigidity is a rational, strategic mechanism adopted by the individual firm in a production-coordination environment.

We continue by developing the pricing conditions necessary to sustain a particular Nash equilibrium, including the pricing conditions associated with the maximum sustainable Nash. Although the adoption of rigid prices by intermediate firms in the context of strategic behavior prevents severe production instabilities, prices in the model represent a two edged sword. Proposition 4 states that pricing limits the ability of the system to sustain coordinated equilibria. For example, the Pareto-optimal production level, Q_p, does not have a sustainable price set. In general, unless the sum of intermediate-input prices is less than an amount specific to the coordinated level of production, that production level, even though a potential Nash equilibrium, will not be sustained. Propositions 5 and 6 state that, with the exception of one coordinated, maximum sustainable production equilibrium called Q_{MAX}, the set of real prices associated with a particular equilibrium is not unique.

Proposition 7 states that given an initial equilibrium below Q_{MAX}, price coordination may be necessary even for coordinated-production expansions. The traditional literature suggests that government can play a critical role in attaining a Pareto-preferred equilibrium by supporting production level confidence. However, Proposition 7 indicates that successful expansion may require the government to undertake specific price coordination.

THE IMPORTANCE OF COORDINATION FAILURES IN MACROECONOMICS

The theoretical and experimental work on coordination-failure models, based on Bryant [1983], Diamond [1982], Hart [1982], and Weitzman [1982], has expanded sufficiently to justify an extended book survey of these models as a new sub-field of macroeconomics [Cooper, 1999]. In contrast to the New Classical Economics perspective in which unemployment arises from inter-temporal substitution of leisure or from failures to distinguish between relative and price level changes, and, in contrast to the Keynesian perspective in which wage/price rigidities play a prominent role, coordination-failure models generate underemployment equilibria from the inability of agents to coordinate their actions successfully in a many-person, decentralized economy [Cooper and John, 1988, 3].

A key feature of coordination-failure models is strategic complementarity, defined as interaction among economic agents in which an increase in the level of activity by one agent will induce other agents to behave similarly. Environments characterized by strategic complementarity have coordination failures because no one agent has an incentive to change activity level so that potential mutual gains from an overall change in agent behavior are not realized [Tesfatsion, 1994]. As Cooper states, "[M]odels of complementarities are really about life inside the production frontier. [T]he distinct possibility for producing more of all goods [exists] if activities can be properly coordinated" [1999, 151-2].

The concept of multiple equilibria has been applied in empirical studies to explain trade patterns and industrial sales patterns [van Ees and Garretsen, 1992, 471-2]. The concept has also been applied (with little support) to the Great Depression [Dagsvik and Jovanovic, 1994] and (more successfully) to British unemployment patterns [Manning, 1990, 160-1]. Empirical work has, however, been limited because of econometric complexities [Silvestre, 1993, 128-130].

In contrast to the embryonic empirical work, the concept of complementarity and coordination has been applied to macroeconomics through several theoretical models. Cooper [1999] provides an extensive review of the models; the following is only a sample.[4]

Multiple equilibria can occur in multiple sector models in which firms have market power and complementarity exists across sectors through income effects [Heller, 1986; Silvestre, 1993; Roberts, 1987]. Expansions in several sectors lead to expansions of other sectors that produce goods purchased by agents operating in the expanding sectors. Multiple equilibria also exist in models with market power and increasing returns to scale in production [Weitzman, 1982; Manning, 1990; Bohn and Gorton, 1993]. Both models generate Keynesian type multiplier effects as well as multiple equilibria that can be Pareto-ranked as illustrated in the models of Heller [1986] and Cooper [1994].

The trading externality model posits that efficiencies resulting from lower transaction (specifically search) costs are generated as markets become thicker with more participants [Diamond, 1982]. Multiple equilibria occur that can be welfare-ranked based on the Pareto criterion.

The production complementarity model—the focus of the present paper—assumes technical complementarity by introducing interaction of agents through the production function [Bryant, 1983; 1993; 1996]. Because of imperfect information and the requirement that things have to fit together, the theoretical model generates multiple equilibria that can be Pareto-ranked. Laboratory experiments have indicated that coordination failures do occur in the production-complementarity environment, and often low-level equilibria are the norm [Van Huyck, Battalio and Beil, 1990].

Bryant [1993, 216-219; 1996, 167-9; 1992] suggests that the production-coordination model isolates the basic team-production problem inherent in an integrated economic system, justifies the development of institutions, and focuses attention on the role of institutions (in contrast to market prices) as the coordinating mechanism in macroeconomics.

The production-coordination model has also been adapted to economic growth and to economic development models [Evans, Honkapohja and Romer, 1998]. Still other applications are to the business cycle [Baxter and King, 1991].

AN OVERVIEW OF THE PRODUCTION-COORDINATION MODEL

Assume a two-sector macro economy in which m independent, monopolistic suppliers trade specialized, intermediate inputs for a final good produced under competi-

tive conditions in a final-good sector consisting of n firms.[5] The final good is employed as a numeraire and has a price equal to one. Strict complementarity exists between the intermediate inputs themselves and between the intermediate inputs and the final good. In addition, intermediate-input and final-good suppliers are owner-manager-laborers. These owner-manager-laborers are the only suppliers of labor, have identical leisure versus final-good preferences, and have diminishing marginal rates of substitution between the final good and leisure.[6]

Formally, the owner's utility functions can be written as:

$$U_{Fi} = U(Y_i, t-L_{Fi}) \tag{1}$$

$$U_{Ij} = U(Y_j, t-L_{Ij}), \tag{2}$$

where U, Y, L, and t refer to the utility level of the owner, the quantity of the final good available to the owner for consumption, the owner's labor applied to production, and the time available to the owner, respectively. The subscript F denotes an owner ($i = 1$ to n) in the final-good sector, and subscript I denotes an owner ($j = 1$ to m) in the intermediate-input sector. Note that, in this real exchange model, Y_i is the amount of final good produced by final-good firm i (from supplying L_{Fi} units of labor) less its payments of the final good to its intermediate-input suppliers. Similarly, Y_j is the total amount of final good payment received by the jth intermediate-input supplier from all final-good suppliers.

The utility functions specified in equations (1) and (2) are assumed to have the usual "well-behaved" properties. In particular, each utility function implies a diminishing marginal rate of substitution of leisure for consumption of the final good. Each owner is assumed to operate under utility-maximizing behavior.

The production functions in each sector are such that: (1) each intermediate-input supplier, j, requires one unit of labor for each unit of the intermediate input produced (raw materials used in the production of intermediate inputs are "free" gifts of nature); and (2) each final-good supplier, i, requires one unit of each type of intermediate-input and one unit of labor per unit of the final good produced. For the intermediate-input firms, the production function can be written as:

$$Q_{Ij} = L_{Ij}, \tag{3}$$

where Q_{Ij} and L_{Ij} are the output of and the amount of labor supplied by the jth firm in the intermediate-input sector respectively. For each of the i final-good firms, the production function can be written as:

$$Q_{Fi} = \min\,(Q_{I1i}, Q_{I2i}, \ldots, Q_{Iji}, \ldots, Q_{Imi}, L_{Fi}), \tag{4}$$

where Q_{Fi}, Q_{Iji}, and L_{Fi} are the output of the ith final-good firm, the quantity of intermediate-input j available to the ith final-good firm, and the labor time used in production by the owner of the ith final-good firm, respectively. In particular, under the trading system described below, unless the final-good firm is certain that a complementary unit of each intermediate input is available, the owner will not buy an additional unit of intermediate input from any firm j or supply an additional unit of labor.

Based on equations (1) and (2), define marginal cost, MC, either for an intermediate-input or final-good firm, as the extra units of final good for consumption required to compensate for the production of one more unit of the intermediate input or final good and thereby supplying one more unit of labor into production. Since in what follows, labor (or forgone leisure) is either the only input in the production process (as in the intermediate-input sector) or the only input that is incorporated into the marginal cost curve (as in the final-good sector), the marginal cost curves for firm i in the final-good sector and for firm j in the intermediate-input sector are, respectively:

$$(5) \qquad MC_{Fi} = dY_i/dQ_{Fi} = [dU_{Fi}/d(t-L_{Fi})]/[dU_{Fi}/dY_i] = dY_i/[-d(t-L_{Fi})]$$

$$(6) \qquad MC_{Ij} = dY_j/dQ_{Ij} = [dU_{Ij}/d(t-L_{Ij})]/[dU_{Ij}/dY_j] = dY_j/[-d(t-L_{Ij})].$$

A diminishing marginal rate of substitution of leisure for consumption of the final good implies an increasing marginal cost curve in both sectors.

The technology implied by the production functions in equations (3) and (4) produces a continuum of coordinated production levels, Q_E, defined by conditions (A) and (B):

(A) $\quad Q_{Fi} = Q_{Ij}/n = Q_E/n,$ $\qquad$ for each firm j (i) in the intermediate-input (final-good) sector, and

(B) $\quad Q_{Ij} = Q_F = Q_E,$ $\qquad$ for each firm j in the intermediate-input sector,

where Q_F is total production (ΣQ_{Fi}) in the final-good sector. The coordinated production levels can range from $Q_E = 0$ to a Pareto-optimal level of production, $Q_E = Q_p$, defined by the additional condition:

$$(B') \qquad 1=\Sigma MC_{Ij}(Q_P) + MC_{Fi}(Q_P/n),$$

for each firm i in the final-good sector and for each firm j in the intermediate-input sector. However, these potential coordinated-production levels may not be Nash equilibria.

For the economy to be at a coordinated production, Nash equilibrium, two critical equilibrium conditions must hold. First, for the production level to be coordinated, each intermediate-input supplier must produce a level of production, Q_E, equal to the common expected production of all other intermediate-input suppliers (conditions (A) and (B)).[7] Second, for this coordinated level of production to be a Nash equilibrium, no firm should have an incentive to alter its production from the common expected level.[8] At a given coordinated production level, whether a firm has an incentive to change production depends on the particular final-good allocation system.

In Bryant's formulation of the production coordination model, agents are allocated the final good by institutional agreement. As long as this institutional agreement allocates the final good in an amount at least equal to the agent's marginal cost,

a similar institution in this model could establish any coordinated-production equilibrium between zero and the Pareto optimal level of production [Bryant, 1983; 1993; 1996].

However, as will be discussed below, if the institutional allocation agreement is replaced by a pricing system, the pricing system may not coordinate suppliers adequately to ensure that the Pareto-optimal equilibrium will be chosen. The pricing system may not even ensure that any coordinated-production level, once initially obtained, is sustainable.

THE TRADING SYSTEM

The trading system underlying the pricing behavior in this model can be described in terms of the following island story. All final-good suppliers are located on a single island, and each intermediate-input supplier is located on a separate island. The intermediate-input suppliers do not communicate with each other during any stage of the trading process. The intermediate-input suppliers communicate with the final-good suppliers only on the trading day. Each period in the trading system consists of the following three stages.

In stage one, each intermediate-input supplier (on its own island) chooses both a production level and a price for its output. The intermediate-input supplier's choice of price and production level is based on the knowledge that: (1) each final-good supplier (on the final-good island) will use the posted prices to determine the profit-maximizing level of each intermediate-input it desires to purchase; and (2) the aggregate level of demand for any intermediate input by final-good suppliers cannot collectively exceed the level of output produced by the intermediate-input supplier(s) choosing the smallest output level.

In stage two, the trading day, each intermediate-input supplier loads its production on a ship and delivers the cargo to the docks on the final-good production island. On delivery, each intermediate-input supplier initially posts its chosen price and begins negotiations with the final-good producers for the ship's cargo. The intermediate-input supplier may attempt to clear the ship's cargo by varying the posted price according to market conditions (flexible-price behavior) or to hold the posted price constant (rigid-price behavior) even if the cargo is not completely sold.

During stage two, each final-good supplier visits the docks and observes the posted prices (specifically, the sum of the posted prices). Each final-good supplier adjusts its demand for each input to the profit-maximizing level; however, they realize that each ship holds only limited and possibly unequal supplies, and thus they are collectively subject to intermediate-input availability constraints. Therefore, to ensure delivery of each and all inputs in the desired quantities, each final-good supplier discusses input availability with the intermediate-input suppliers but places an order only if each supplier can guarantee a matching level of intermediate inputs.

In the final stage (stage three), the intermediate-input suppliers release their cargos to the contracting final-good firms at the market prices. The intermediate-input suppliers costlessly dispose of any intermediate-input stock not sold. The intermediate-input suppliers wait in port until the final-good producers transform the intermediate-inputs into the final good and make the contracted payments. The intermediate-input suppliers then return to their own islands with these final-good payments.

BEHAVIOR UNDER FLEXIBLE AND RIGID REAL-PRICE REGIMES

Final-Good Supplier Behavior

To establish the behavior of final-good firms in stage two under this trading system, first define the marginal residual, MR_{Fi}, for final-good firm i as the final-good output remaining for firm i to consume after it supplies one more unit of labor to produce one more unit of final good, and pays each intermediate-input firm for the one extra input unit required to complement this extra unit of labor. Therefore, employing the final good as the numeraire:

(7) $$MR_{Fi} = 1 - \Sigma P_{Ij},$$

where "1" is the price of the final good, P_{Ij} is the price of firm j's intermediate input, and Σ is the summation over all j.

Because of the competitive nature of the final-good industry, in stage two of the trading system each final-good supplier considers the posted prices of the intermediate-inputs as fixed. Given these fixed prices, each final-good firm, i, attempts to expand its labor input, L_{Fi}, its intermediate-input use, Q_{Iji}, and thus its final-good production, $Q_{Fi} = L_{Fi} = Q_{Iji}$, until its marginal residual from supplying an extra unit of labor (producing an extra unit of final good) is equal to its marginal cost. Therefore, condition C:

(C) $$MR_{Fi} (= 1 - \Sigma P_{Ij}) = MC_{Fi}, \qquad \text{for each firm } i \text{ in the final-good sector,}$$

is added to conditions (A) and (B) described above. Using equations (5) and (7), condition (C) can be written as:

(8) $$1 - \Sigma P_{Ij} = [dU_{Fi}/d(t-L_{Fi})]/dU_{Fi}/dY_i = dY_i/[-d(t-L_{Fi})].$$

Given the utility function of final-good supplier i, its level of final good supplied, its level of labor supplied, and its level of each intermediate-input demanded are each a function of the sum of the intermediate-input prices:

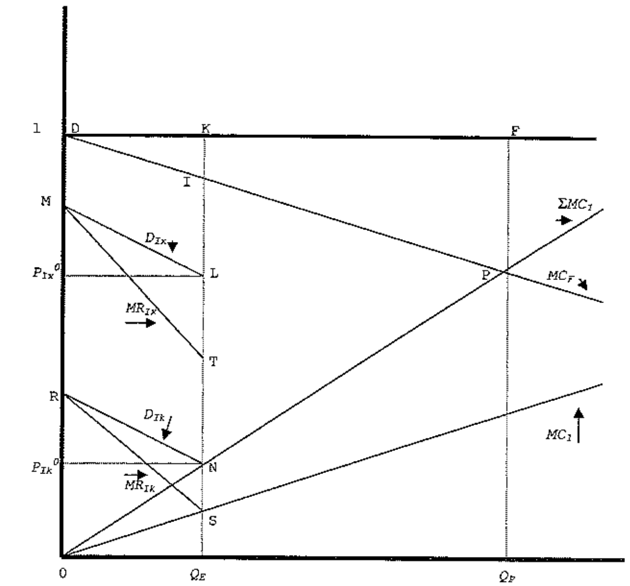
(9) $$Q_{Fi} = L_{Fi} = Q_{Iji} = h(\Sigma P_{Ij}).$$

Because each final-good firm equates $MR_{Fi} = 1 - \Sigma P_{Ij}$ to MC_{Fi}, the supply curve for each final-good firm is identical to its marginal cost.

In a manner identical to the procedure employed in a standard microeconomic theory course, the marginal cost curves of the individual final-good suppliers can be horizontally summed to obtain the desired aggregate (market) level of final good produced, the corresponding desired aggregate (market) level of labor supplied, and the corresponding aggregate (market) level of each intermediate input demanded by the final-good sector as a function of the sum of the intermediate-input prices:

(10) $$Q_F = L_F = Q_{Ij} = nh(\Sigma P_{Ij}).$$

FIGURE 1
Sub-Optimal Nash Equilibrium



Given identical and linear marginal cost curves for the final-good suppliers, condition (C) and equation (10) are illustrated in Figure 1. Measuring vertically downward from the horizontal line DKF, which is positioned one unit above the horizontal axis, DIP is the horizontal sum of the individual final-good firm's marginal cost curves. Therefore, if the final-good sector were producing Q_E, KI would be the marginal cost of a final-good supplier. If the sum of the intermediate-input prices were equal to $P_{Ix}^0 + P_{Ik}^0 = Q_E$I, then the marginal residual for any final-good firm would be $1 - Q_E$I. The marginal residual would equal the marginal cost, KI, at aggregate final-good production level Q_E, the optimal production level for the final-good sector given this sum of intermediate-input prices.

This analysis assumes that, in stage two, each final-good firm can obtain from each intermediate-input firm all the inputs the final-good firm desires at a given (posted) intermediate-input price. However, constraints imposed by the current coordinated output level by the intermediate-input sector may prevent final-good firms from obtaining desired quantities of intermediate inputs at a fixed ΣP_{Ij}. Under these excess demand conditions, at the current coordinated-output level, the intermediate-input suppliers will in stage two increase their prices until, in equilibrium, the sum of the intermediate-input prices is such that the excess of the marginal residual over the marginal cost for each firm in the final-good sector is zero. That is, the rule MR_{Fi}

$= 1-\Sigma P_{Ij} = MC_{Fi}$ occurs both by attempted quantity adjustments by the final-good firms and resulting price adjustments by the intermediate-input firms.

Intermediate-Input Supplier Behavior

Since a major focus of this paper is whether a set of real prices will sustain a coordinated production level Q_E, the production and pricing behavior of the utility-maximizing intermediate-input firm can be most meaningfully discussed by initially assuming that a coordinated production level at Q_E existed in the previous period. The behavior of intermediate-input firm k in stage one of the current period will then be developed. Therefore, the following discussion of intermediate-input supplier behavior assumes that in the previous period conditions (A), (B), and (C) held at Q_E:

(A) $Q_{Fi} = Q_{Ij}/n = Q_E/n,$ for each firm j (i) in the intermediate-input (final-good) sector;

(B) $Q_{Ij} = Q_F = Q_E,$ for each firm j in the intermediate-input sector; and

(C) $MR_{Fi} (= 1-\Sigma P_{Ij}) = MC_{Fi},$ for each firm i in the final-good sector.

Conditions (A), (B) and (C) are illustrated in Figure 1. Assume that only two intermediate-input firms exist, supplier x and supplier k, and that each produced intermediate-inputs equal to Q_E in the previous period. Supplier x priced its input at $P_{Ix}{}^0$, and supplier k priced its input at P_{Ik}^0, where $P_{Ix}^0 + P_{Ik}^0$ equals Q_EI. The final-good sector purchased the intermediate inputs and produced Q_E. Each final-good supplier had marginal cost, KI, and marginal residual $1 - (P_{Ix}^0 + P_{Ik}^0) = 1-Q_E\text{I}$ (= KI).

Given this previous period production equilibrium position, intermediate-input firm k must determine whether either increasing or decreasing its production can increase its utility in stage one of the current period, given that the other firms do not alter their production. The following analysis will demonstrate that intermediate-input supplier k (a monopolist) faces a segmented, inverse demand curve defined as:

$$P_{Ik} = P_{Ik}(\Sigma' P_{Ij,}\ MC_{Fi}(Q_k)),\ \text{for } 0 < Q_k < Q_E \tag{11}$$

where the summation Σ' is for j not equal to k;

$$P_{Ik} = P_{Ik}^0,\ \text{for } Q_{Ik} = Q_E;\ \text{and} \tag{12}$$

$$P_{Ik}^0 \geq P_{Ik} \geq 0,\ \text{for } Q_{Ik} > Q_E, \tag{13}$$

where P_{Ik}^0 is the price specified by intermediate-input firm k at output Q_E. The price P_{Ik}^0 serves to locate the position (in contrast to the slope) of the demand curve for intermediate-input firm k.[9] The specific form of this segmented, inverse demand curve

will depend on whether real prices are flexible or rigid in stage two of the trading story.

First, consider the flexible real-price case. If, in stage one, firm k decides to produce Q_{Ik} where $Q_{Ik} > Q_E$ (equation (13)), because of complementarity, firm k's intermediate-input would be in excess supply in stage two of the period (given the assumption that intermediate-input firms other than firm k continue to produce Q_E). In a perfectly flexible price environment, the price of firm k's intermediate input in stage two would drop toward zero. However, in contrast to the standard case in which a lower real price increases the quantity demanded, in a production-coordination model, a reduction in price by firm k would not increase the quantity demanded of its product. That is, firm k's demand curve in stage two is perfectly inelastic at output level Q_E for increases in output above Q_E. Therefore, intermediate-input firm k would have no incentive to produce a level of output greater than Q_E in stage one.

On the other hand, given the assumption that other intermediate-input firms will leave their output unchanged, if, in stage one, firm k decides to produce slightly less than the coordinated level Q_E, the only relatively scarce intermediate input in stage two of the trading story would be the output of firm k. The output of all non-k intermediate-input suppliers would be in surplus. In a flexible-price environment, during stage two of the trading story firm k would raise its real price while the non-k firms would lower their real prices. Again, in contrast to the standard case in which a lower real price would increase the quantity demanded, in a production-coordination model, a lower real price by non-k intermediate-input suppliers will have no impact on their quantity demanded as long as firm k maintains its output below Q_E. In other words, the demand curve for non-k suppliers is perfectly inelastic at level Q_{Ik} as long as firm k is the constraining (lowest production) firm.

More formally, under perfect price flexibility in which the prices of non-k intermediate-input firms drop to zero, a slight reduction in output by firm k equal to $\ni$ would enable firm k to increase its price by $\Sigma' P_{Ij}$ (Σ' = summing for all j not equal to k) to $1-MC_{Fi}(Q_{Ik})$. In effect, under perfect price flexibility, by raising its real price as other intermediate-input firms lower theirs, firm k is redistributing revenue, $(\Sigma' P_{Ij})Q_{Ik}$, from other firms in the intermediate-input sector to itself. As $\ni \to 0$, the increase in firm k's price to $1-MC_{Fi}(Q_{Ik})$ would, in the limit, occur at output Q_E. This increase in price shifts the demand curve for firm k from $P_{Ik}{}^0$ to $1-MC_{Fi}(Q_E)$ at output Q_E and increases revenue in the limit by $(\Sigma' P_{Ij})Q_E$.[10]

Because of the redistribution of revenue that results from the slight decrease in output, the higher price corresponding to the reduction of output at Q_E is called the price-redistribution effect, which is illustrated in Figure 1. In Figure 1, holding firm x's output constant at Q_E, let firm k lower its output slightly below Q_E. As a result, as firm x, responding to its excess supply condition, lowers its price toward zero, firm k could raise its price toward Q_EI, gaining the revenue, $P_{Ix}{}^0 Q_E$, that firm x loses.

In addition to the shift in the demand curve for firm k at Q_E that results from any price-redistribution effect, by reducing output further, firm k can move along its demand curve and increase its real price because of the rent-capture effect. This effect occurs because as firm k decreases its output below Q_E the marginal cost of the final-good sector falls.

More formally, the rent-capture effect operates as follows. Prior to the production reduction by firm k, each final-good firm, i, equates its marginal residual to its marginal cost, $1-\Sigma P_{Ij} = MC_{Fi}$ (evaluated at the set of intermediate-input prices that prevailed at Q_E prior to the reduction in output by firm k). Therefore, the excess of the marginal residual over final-good firm i's marginal cost, $(1-\Sigma P_{Ij}-MC_{Fi})$, is initially zero. Abstracting from the price-redistribution effect on the non-k firms' prices, a reduction in firm k's production below Q_E will increase this excess marginal residual by an amount equal to the derivative of the final-good marginal cost curve, $dMC_{Fi}(Q_{Ik})/dQ_{Ik}$. Given that intermediate-input firm k reduces its production below Q_E, this excess marginal residual is extracted by firm k through an increase in its real price. This power of firm k to further increase its price as it reduces production below the coordinated-output level Q_E is called the rent-capture effect.

In summary, given perfect real-price flexibility, as firm k lowers its supply, if prices by non-k intermediate-input firms drop to zero in the face of excess supply, k's demand curve would first shift upward to $P_{Ik} = 1-MC_{Fi}(Q_E)$ because of the price-redistribution effect and then would slope upward by $dMC_{Fi}(Q_{Ik})/dQ_{Ik}$ because of the rent-capture effect. That is, equations (11) through (13) (firm k's inverse demand curve) would take the following form:

(11a) $$P_{Ik} = 1-MC_{Fi}(Q_k), \text{ for } 0 < Q_k < Q_E;$$

(12) $$P_{Ik} = P^0_{Ik}, \text{ for } Q_{Ik} = Q_E; \text{ and}$$

(13a) $$P_{Ik} = 0, \text{ for } Q_k > Q_E.$$

For example in Figure 1, after the price-redistribution effect has been completed, supplier k's demand curve (reflecting the rent-capture effect) would be given by the line segment DI determined by the final-good sector's marginal cost curve.

Therefore, for $0 < Q_k < Q_E$ and the flexible price case (both the redistribution and rent-capture effect are operative), total revenue for firm k is:

(14) $$TR_{Ik}(Q_k) = [1-MC_{Fi}(Q_k)]Q_k,$$

and marginal revenue is:

(15) $$MR_{Ik}(Q_k) = [1-MC_{Fi}(Q_k)] - [dMC_{Fi}(Q_k)/dQ_k]Q_k.$$

The non-constraining (non-k) intermediate-input firms would eventually learn that real-price reductions are ineffective in increasing quantity demanded and instead would use quantity adjustments, with downwardly-rigid real prices, when excess supply exists. Therefore, the degree to which firm k's demand curve shifts in response to a slight reduction in its output depends on the degree of price flexibility, specifically, the price response of non-k firms to the excess supply that results from the reduction in output by firm k.

Now, consider the rigid real-price case. If, in stage two of the trading story, all intermediate-input firms hold their prices rigid in the face of excess supply, firm k's demand curve would not shift and points on it would be based only on the rent-capture effect. That is, equations (11) through (13) (firm k's inverse demand curve) would take the following form:

(11b) $$P_{Ik} = 1-\Sigma' P_{Ij}-MC_{Fi}(Q_k), \text{ for } 0 < Q_k < Q_E;$$

(12) $$P_{Ik} = P^0_{Ik}, \text{ for } Q_{Ik} = Q_E; \text{ and}$$

(13b) $$P_{Ik} = P^0_{Ik}, \text{ for } Q_k > Q_E.$$

The rent-capture effect in the rigid real-price case is illustrated in Figure 1. If no price-redistribution effect occurs, supplier k's demand curve (reflecting the rent-capture effect) would be given by the line segment RN, whose slope is determined by the slope of the final-good sector's marginal cost curve (along section DI).

For $0 < Q_k < Q_E$ and the fixed price case (only the rent-capture effect is operative), total revenue for firm k is:

(14a) $$TR_{Ik}(Q_k) = [1-\Sigma' P_{Ij}-MC_{Fi}(Q_k)]Q_k,$$

and marginal revenue is:

(15a) $$MR_{Ik}(Q_k) = [1-\Sigma' P_{Ij}-MC_{Fi}(Q_k)] - [dMC_{Fi}(Q_k)/dQ_k]Q_k.$$

In Figure 1, supplier k's marginal revenue would be given by RS.

THE EFFECTS OF PRICE FLEXIBILITY AND PRICE RIGIDITY

The first three propositions relating to the effect of flexible versus rigid pricing by intermediate-input firms follow directly from the analysis in the previous section.

Proposition 1: A flexible, real-price system fails to improve the welfare properties of the economy and can actually cause a deterioration of welfare by introducing serious production instabilities. With perfect real-price flexibility, the perceived increase in total revenue from the price-redistribution effect combined with the perceived decline in total cost will create an incentive for each intermediate-input firm to undertake a slight reduction in output below any coordinated output level. Because this incentive exists for any positive level of coordinated output, in the limit, output will fall to zero. Therefore, the price-redistribution effect resulting from price flexibility creates serious instability in a production-coordination model with real exchange.

Proposition 2: Downwardly inflexible prices as a response to demand constraints may result in sustainable, Pareto-preferred outcomes. In an economy with real-price rigidity, a reduction in output by firm k in the intermediate-input sector will generate only a rent-capture effect. Therefore, whether firm k has an incentive to reduce production depends on whether at $Q_k = Q_E$ marginal revenue, described by equation (15a), is less than marginal cost, (6a) $MC_{Ik}(Q_k) = [dU_{Ik}/d(t-L_{Ik})]/dU_{Ik}/dY_k = dY_k/[-d(t-L_{Ik})]$.

If marginal revenue exceeds or equals marginal cost, firm k would have no incentive to reduce production below the coordinated output level. However, if marginal revenue were less than marginal cost for any firm k in the intermediate-input sector, firm k would reduce production.

Therefore, a coordinated production level Q_E is a Nash equilibrium only if marginal revenue equals or exceeds marginal cost for all firms in the intermediate-input sector. That is, in addition to conditions (A) through (C), condition (D) must hold:

(D) $MR_{Ij} \geq MC_{Ij}$, for each firm j in the intermediate-input sector.

A stable Nash equilibrium under rigid real prices is illustrated in Figure 1. In Figure 1, if MC_I is the marginal cost for firm k (x), then at Q_E marginal revenue is equal to (greater than) marginal cost for firm k (x). Therefore, firm k (x) has no incentive to reduce production from the coordinated equilibrium at Q_E.

Proposition 3: Price rigidity is a rational, strategic mechanism adopted by the individual firm in a production-coordination environment. In an economy with production-coordination problems, because a price reduction would not increase the level of sales for an intermediate-input supplier who is not the "short" supplier, rational behavior for an individual supplier facing excess supply is to refuse to lower its price. Maintaining rigid prices in the face of excess supply will prevent strategic behavior by other suppliers from reducing its share of any marginal residual (i.e., rigid prices prevent the redistribution effect). Therefore, prices become downwardly rigid as a result of protective strategic behavior by individual suppliers.

MAXIMUM NASH EQUILIBRIUM, PRICE SETS, AND PARETO-OPTIMALITY

The complete conditions for coordination-production Nash equilibrium at Q_E can be expressed as follows:

(A)	$Q_{Fi} = Q_{Ij}/n = Q_E/n$,	for each firm j (i) in the intermediate-input (final-good) sector;[11]
(B)	$Q_{Ij} = Q_F = Q_E$,	for each firm j in the intermediate-input sector;
(C)	$MR_{Fi}\ (= 1-\Sigma P_{Ij}) = MC_{Fi}$,	for each firm i in the final-good sector; and
(D)	$MR_{Ij} \geq MC_{Ij}$,	for each firm j in the intermediate-input sector.

Each of these conditions was established in the previous sections.

Assume that the economy is producing a coordinated-output level Q_E as described by the above conditions. This section will demonstrate Propositions 4 through 6.

Proposition 4: For Q_E above a critical level, Q_{MAX}, no intermediate-input price set exists that satisfies conditions (A) through (D), and thus output levels above Q_{MAX} cannot be Nash equilibria. From equations (11b) and (15a), when all other firms are producing at coordinated-equilibrium Q_E, the marginal revenue for an intermediate-input firm j that is producing $Q_{Ij} < Q_E$ is $MR_{Ij} = P_{Ij} - [dMC_{Fi}(Q_{Ij})/dQ_{Ij}]Q_{Ij}$. From condition (D) for a Nash equilibrium at Q_E, $MR_{Ij}(Q_{Ij}) \geq MC_{Ij}(Q_{Ij})$ or $P_{Ij} - [dMC_{Fi}(Q_{Ij})/dQ_{Ij}]Q_{Ij} \geq MC_{Ij}(Q_{Ij})$ for each j. Rearranging:

(16) $P_{Ij} \geq MC_{Ij}(Q_{Ij}) + [dMC_{Fi}(Q_{Ij})/dQ_{Ij}]Q_{Ij} = S(Q_{Ij})$.

In addition, from condition (C), for a Nash equilibrium at Q_E, $1-\Sigma P_{Ij} = MC_{Fi}(Q_{Ij})$ or by rearranging:

(17) $\Sigma P_{Ij} = 1 - MC_{Fi}(Q_{Ij}) = T(Q_{Ij})$.

As $Q_{Ij} = Q_E$ increases, T and therefore ΣP_{Ij} must decrease. From equation (16), summing over all j in the intermediate-inputs sector, $\Sigma P_{Ij} \geq \Sigma S(Q_{Ij})$. Further as $Q_{Ij} = Q_E$ increases, $\Sigma S(Q_{Ij})$ must also increase. Therefore, $\Sigma S(Q_{Ij})$ is a monotonically increasing function of Q_E, and $T(Q_{Ij})$ is a monotonically decreasing function of Q_E. For output levels beyond the point where these two functions intersect, the condition $\Sigma P_{Ij} \geq \Sigma S(Q_{Ij})$ is violated. Since this condition follows from condition (D), for output levels beyond this point, Nash equilibria cannot exist for these output levels. More specifically, the maximum output level Q_E for which a Nash equilibrium can exist is that output level, Q_{MAX}, where the two functions intersect, i.e., $T(Q_{MAX}) = \Sigma S(Q_{MAX})$.

Does Q_{MAX} correspond to Pareto-optimal production, Q_P? For a Pareto-optimal equilibrium, conditions (A) through (C) hold at the Pareto optimal output level $Q_E = Q_P$, and condition (D) is replaced by:

(D') $P_{Ij} = MC_{Ij}(Q_P)$, for each firm j in the intermediate-input sector.

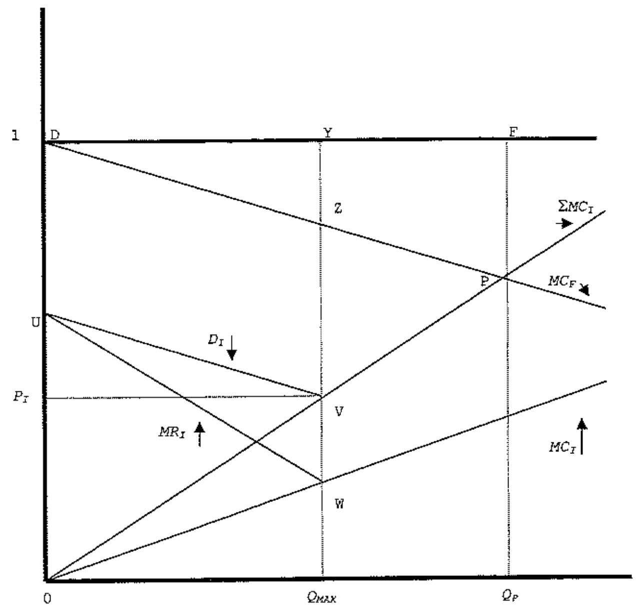
Conditions (C) and (D') are analogous to the marginal conditions for Pareto-optimality in standard welfare economics.

Because intermediate-input firms operate in imperfectly competitive markets, at the maximum Nash equilibrium, $P_{Ij} > MR_{Ij} = MC_{Ij}$. Intermediate firms will have no incentive to produce at a level where price is equal to their marginal costs (and marginal revenue is less than marginal cost). Therefore condition (D') does not hold even at the maximum Nash equilibrium.

Given the simplifying assumptions in Figure 1, Figure 2 illustrates both the maximum Nash at Q_{MAX} and the Pareto-optimal level of production at Q_P (also illustrated in Figure 1). Let both intermediate-input suppliers, x and k, have price, demand, marginal revenue, and marginal cost equal to P_I, D_I, MR_I, and MC_I, respectively. In addition, $1-2P_I = 1-Q_{MAX}Z$ is the marginal residual and ZY is the marginal cost of a final-good firm. Therefore, Q_{MAX} is a Nash equilibrium. In addition, because conditions (C) and (D) are holding as strict equalities, no firm has an incentive to expand beyond Q_{MAX}. However, given that ΣMC_I is the vertical sum of the marginal cost of firms x and k, Pareto-optimal production is at $Q_P > Q_{MAX}$ where $1 - MC_{Ix} - MC_{Ik} = MC_{Fi}$.

FIGURE 2

Maximum Nash Equilibrium and Pareto-Optimal Production



Even though a Pareto-optimal equilibrium is not feasible, equilibrium output levels can be Pareto-ranked by comparing various output levels to the level associated with Pareto-optimality. The closer any equilibrium level of output is to the Pareto-optimal level, the more Pareto preferred that output level would be. Since Q_{MAX} is the highest equilibrium output that is feasible, it is the Pareto-preferred coordinated-output level.

Proposition 5: At the unique, coordinated-output level, Q_{MAX}, the set of intermediate-input prices will be unique, and Q_{MAX} will be the maximum, Nash equilibrium. From Proposition 4, at $Q_{MAX,}\,\Sigma S(Q_{Ij}) = T(Q_{Ij}) = \Sigma P_{Ij}$. However, Nash equilibrium condition (C) implies that:

(16) $$P_{Ij} \geq MC_{Ij}(Q_{Ij}) + [dMC_{Fi}(Q_{Ij})/dQ_{Ij}]Q_{Ij} = S(Q_{Ij}).$$

If the strict inequality holds, the condition $\Sigma S(Q_{Ij}) = T(Q_{Ij}) = \Sigma P_{Ij}$ is violated. Therefore, $P_{Ij} = S(Q_{Ij})$ at Q_{MAX}, and P_{Ij} for all j is unique at Q_{MAX}.

Proposition 6: Levels of Q_E below Q_{MAX} can be Nash equilibria; however, the set of intermediate-input prices associated with the equilibrium will not be unique. This proposition is a corollary of Proposition 5. For output levels below Q_{MAX}, equation (16) holds as an inequality for at least some firms in the intermediate-input sector. This inequality implies that the prices in the intermediate-input sector are not unique for Q_E below Q_{MAX}. For example in Figure 1, the price set of $P_{Ix}{}^0$ and $P_{Ik}{}^0$ are only two of many possible price sets compatible with the Nash equilibrium at Q_E.

PRICING CONDITIONS FOR A SUCCESSFUL COORDINATED EXPANSION

Events promoting production coordination, whether the result of government policy or private sector developments, require suitable pricing conditions for the improved production coordination to result in economic expansion. Given an initial output level Q_E below Q_{MAX}, for a production-coordinating action to successfully expand output to a Pareto-preferred level, no intermediate-input firm, prior to the expansion, can satisfy condition (D) as a strict equality (i.e., marginal revenue is equal to marginal cost). If such an intermediate-input firm did exist, its expansion would cause its marginal cost to exceed its marginal revenue. For example, in Figure 1 intermediate-input supplier k has marginal revenue equal to marginal cost at Q_E. This firm would have no incentive to expand even if expansion was otherwise coordinated. Therefore, only as long as condition (D) is satisfied as a strict inequality for each intermediate-input supplier can a coordinated production expansion successfully move the system to a Pareto-preferred Nash equilibrium. The following proposition follows from this analysis.

Proposition 7: Given an initial equilibrium below Q_{MAX}, price coordination may be necessary even for coordinated production advances. If, at the initial output level, marginal revenue equals marginal cost for some intermediate-input firm, this firm would expand only if it received an increase in its price. However, a rise in one intermediate-input firm's price would require a reduction in the price of other intermediate-input firms. A coordinated production expansion would thus require accompanying price coordination. Specifically, if these respective increases and decreases in intermediate-input prices occur such that ΣP_{Ij} remains at a level continuing to satisfy $1-\Sigma P_{Ij} = MC_{Fi}(Q_E)$ for each final-good firm, then these real-price changes would provide an incentive for all firms in each sector to jointly expand.

For example, in Figure 1 at coordinated production equilibrium Q_E, marginal revenue exceeds marginal cost for intermediate supplier x, but marginal revenue equals marginal cost for supplier k. Therefore, intermediate-input supplier k would be willing to expand to a higher coordinated production equilibrium only if its price increased (effectively its demand and marginal revenue curves shift up), thus forcing the price of supplier x to fall (effectively its demand and marginal revenue curves shift down).

It is not clear, however, that market incentives would lead to such price-coordinating changes. Therefore, by Proposition 7, in a world characterized by production-coordination failure, pure production-coordinating policy actions that are intended to be expansionary will not succeed unless accompanied by incentives for economic units to engage in the appropriate price coordination. Specifically, intermediate-input firms that have marginal revenue greater than marginal cost must reduce their price in the face of expanding demand and production (even though as described above they would refuse to lower prices when subject to sales constraints) to allow intermediate-input firms that have marginal revenue equal to marginal cost to increase their price and marginal revenue.

CONCLUSION

This paper demonstrates that, in economies characterized by production coordination failures, price-setting firms, corresponding to excess supply resulting from the strategic behavior of other firms, will have an incentive to maintain real-price rigidity. This paper shows that such real-price rigidity results in Nash equilibria associated with nonzero output levels. Therefore, in contrast to Bryant's pathological result in a Walrasian market environment, this paper argues that a market mechanism can avoid a Nash equilibrium with zero production.

In addition, this paper concludes that markets with production-coordination failures and rigid real prices will not generate a configuration of real prices for which a Pareto-optimal level of output is a Nash equilibrium. Instead, a model with these features is associated with a Pareto-sub-optimal maximum level of output at a unique set of real prices. At output levels below this maximum level of output, Nash equilibria are associated with a non-unique set of prices.

Finally, the pricing features of this model require a degree of pricing coordination to sustain output levels generated by production-coordination actions. Because of these features, this paper can be regarded as a contribution to both the price and production-coordination literature.

The strategic behavior in this production coordination model that suggests an advantage for inflexible real prices (and price coordination) supports a strand of the New Keynesian literature that emphasizes real-price rigidity. The implicit contract, insider-outsider, and efficiency-wage models generate real-wage rigidity by proposing a non-market-clearing function for real intermediate-input prices. This paper argues that price flexibility results in losses to the supplier that changes prices in response to excess supply. This result may offer an even stronger justification for fixed real prices than those models that indicate that price flexibility provides gains too small to offset the costs of price adjustment [Romer, 1993, 8-11].

NOTES

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1. Silvestre [1993] argues that, because of the assumption of instantaneous price adjustments in coordination models, these models do not formally belong to the sticky-price models of the New Keynesians. However, Colander [1992], van Ees and Garretsen [1992], and Mischel [1998] believe that, although sticky prices do not cause coordination failure, coordination failure models are consistent with sticky prices. See Gordon [1990], Mankiw and Romer [1991], Colander [1992], van Ees and Garretsen [1992], and Davidson [1992] for various views on taxonomy and labeling. For example Colander [1998] prefers the Post Walrasian label for coordination models.
2. Roberts [1987] has agents endogenously determine prices in a coordination-failure model.
3. This paper follows Colander's [1995] suggestion to incorporate coordination into the production function.

4. See Cooper and Johns [1988], van Ees and Garretsen [1992], Silvestre [1993], and Cooper [1999] for references, formal definitions of concepts, and an overview of the various model types.
5. See Silvestre [1993] for a survey of the role of imperfect competition in coordination models.
6. Because of diminishing marginal rate of substitution between final goods and leisure, as the output of the intermediate or the final-good supplier expands, the owner-manager-laborer must be compensated at the margin with greater amounts of the final good.
7. Although this paper does not formally model how expectations are coordinated to yield the common expected production level, mechanisms such as public policy actions or private and/or public sector economic forecasts may coordinate expectations to yield a coordinated production result [Guesnerie, 1993; Bryant, 1992]. Also, see Iwai [1981, Ch. 2] for a theoretical development of expectation formation.
8. Because the dynamics needed for equilibrium selection are not developed, the analysis of supply coordination has been principally in terms of behavior in an equilibrium state [van Ees and Garretsen, 1992, 471-2]. Experimental research indicates that a Nash equilibrium is a good predictor of behavior but that the Pareto-optimal Nash is not always the outcome. See Van Huyck, Battalio and Beil [1990], Cooper, DeJong, Forsythe and Ross [1990], Straub [1995], and Van Huyck, Cook and Battalio [1997] for examples of and references to experimental models and their results.
9. This paper does not formally model the determination of P_{Ik}^{o} other than to note that it is based on the past history of the interaction of the firms in the intermediate sector and the relative bargaining power acquired by these firms as a result of that interaction.
10. Because the increase in price cannot occur unless firm k lowers its output below Q_E, the altered demand curve for firm k would have a discontinuity at output Q_E.
11. Given an equal and rising marginal cost structure for all final-good firms, final-good firms that use a disproportionately large (small) amount of intermediate inputs would experience a negative (positive) marginal residual, which would encourage them to contract (expand) resource use.

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