RETURNS TO SPECIALIZATION, TRANSACTION COSTS, AND THE DYNAMICS OF INDUSTRY EVOLUTION

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ABSTRACT. We develop a model of industry evolution to study the process of vertical integration and disintegration (specialization). Absent industry level increasing returns, an industry will be vertically integrated in the long run if and only if transaction costs are greater than the costs of coordinating within a firm. However, convergence to the efficient industry structure may take very long and may not be monotonic: For long periods of time, the industry structure may diverge from its long run equilibrium of vertical integration. When transaction costs depend on the extent of specialization, there can be path dependence and inefficiency even in the very long run. Even when specialization is efficient, the industry may become vertically integrated.

I INTRODUCTION

When more than one economic activity is required to produce a good, firms can specialize or integrate all the necessary activities in one organization. These choices are widely believed to condition the profits a firm earns. A substantial literature has argued that vertical integration takes place when the costs of transacting across firm boundaries outweigh the benefits of specialization (e.g. Coase [1937], Williamson [1979]). However, transaction costs may themselves depend on the extent to which other firms are specialized and thus, on the extent to which the industry is vertically integrated. This argues for analyzing vertical integration at the level of the industry and not just as a firm level phenomenon.

The economics of specialization has old roots in the economics literature, going as far back as Adam Smith's idea of division of labor. A division of labor permits workers to focus on tasks where they enjoy a comparative advantage, and thus, increases the efficiency of the system as a whole. Although initially intended to apply to the division of tasks within a factory, the idea of division of labor can be easily extended to the division of labor amongst firms, rather than among workers inside a firm. However, unlike in a factory, the mechanisms for coordinating the division of tasks across firms is not the Chandlerian "visible hand" but rather its less visible Smithian counterpart. How effective are price signals at coordinating the decisions of firms and guiding the industry towards the long run cost minimizing structure when the future is uncertain?

The point of departure for our paper is that the choices of firms may be interdependent. If firms behave strategically (e.g., Farrell, Monroe and Saloner [1998]) or

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if they are boundedly rational as in this paper, these interdependencies may cause industry structure to evolve away, at least for some time, from the steady state structure. In this paper we explore how the degree of vertical integration in an industry evolves over time. Absent industry level increasing returns, an industry will be vertically integrated in the long run if and only if integration is efficient in the sense that it minimizes long run costs. However, convergence to the efficient industry structure may take very long and may not be monotonic: There are asymmetries, albeit transient, between the entry processes for specialized and integrated firms. For instance, when specialization and vertical integration are equally efficient, specialization turns out to be the more likely outcome. Further, when transaction costs themselves fall with the extent of specialization, there can be path dependence and inefficiency even in the very long run (e.g., David [1985], Arthur [1989]).[1] Even when specialization is efficient, the industry may become vertically integrated.

We develop a simple model where the final good requires two components. For ease of exposition we shall call them hardware and software, each produced by a separate activity. There are three key elements of our story. The first recalls a long-standing advantage of specialization first noted by Charles Babbage more than a century ago⇔Specialization allows agents (workers, firms) to concentrate on activities that they do best.[2] Whereas, an integrated firm has to master an array of activities and processes, a specialized firm needs to master only a few. In our model, this implies that an integrated firm is less likely to arise than equally competent and separate specialized firms.

Second, when a firm has different levels of efficiency in the two activities, relying upon its own resources can act as a drag on the more efficient activity. This effect – called here the division of labor effect – is incorporated into our model by assuming increasing marginal costs for the two activities. A firm that carries out both activities internally cannot take the full advantage of the activity in which it is more efficient because it is forced up the marginal cost curve of the less efficient activity. By specializing in the more efficient activity it would, in essence, face a flat marginal cost curve for the other activity (e.g. Stigler, 1951).[3]

The final element of our story appeals to the coordination problems in the dynamic process of division of labor. Division of labor implies trade between specialized agents. Hence, the payoff to specialization for any firm depends on the efficiency of the sector supplying complementary products. If so, an industry which becomes vertically integrated early in its history may prove to be very difficult for a specialized firm to enter, thereby preserving vertical integration. In this set up, the coordination problem arises in part because a specialized entrant cannot coordinate with another entrant producing the complementary input. This coordination effect is important either when the two types of specialized firms differ

[1] See Katz and Shapiro [1994] and Besen and Farrell [1994] for a discussion of positive feedbacks due to network externalities and other issues related to standardization.

[2] "... (T)he master manufacturer, by dividing the work to be executed into different processes, each requiring different degrees of skill or of force, can purchase exactly that precise quantity of both which is necessary for each process; *whereas, if the whole work were executed by one workman, that person must possess sufficient skill to perform the most difficult, and sufficient strength to execute the most laborious, of the operations into which the art is divided."* (Babbage, 175-6, quoted in Rosenberg [1994: 28], italics ours.)

[3] In our model, specialization in one activity does have an opportunity cost in that the firm may still earn positive rents from its activity in the other organizational form.

in number and cost (as may happen in the course of industry evolution) or when there are externalities, such as when transaction costs fall with the level of industry specialization. In the latter case, coordination failure can lead to inefficiently high integration.

The history of several industries illustrates these dynamic forces. In the computer industry, IBM's decision to unbundle its software business from its hardware business, and license its operating system from Microsoft is said to have been instrumental in the creation of the software industry (see for example, Dorfman [1987], Langlois [1992], Cortada [1993]). Likewise, one sees evidence that initial conditions in the evolution of the disk-drive industry may have affected the pattern of specialization in that industry.[4] Arora and Gambardella [1998] document that the emergence of specialized engineering firms – a class of firms that specialized in the design of chemical process plants – was accompanied by an increase in the number of chemicals producers.

In many industries, division of labor was facilitated by the emergence of well defined standards that allowed specialized firms to produce complementary products that could be "mixed-and-matched". Recent industry case studies of computer software (Cottrell [1996], Mowery [1996]), computers (Bresnahan & Malerba [1997], Bresnahan & Greenstein [1995]), disk-drives (Christensen [1995]) and semiconductors (Langlois & Steinmueller [1997]) suggest that the emergence of standards coincided with the an increase in the number of specialized producers of components.

Farrell, Monroe and Saloner [1998], provide a model of industry structure similar in spirit to one provided in this paper. Assuming zero transaction costs, they find that industry configuration with specialization is more efficient. They also find that when there are many producers, industry configurations with specialization yield lower profits and hence are less likely. Unlike Farrell *et al.*, we explicitly investigate the dynamics of industry structure in a competitive market setting, albeit with boundedly rational firms. We explore how differences in entry and exit prospects of specialized and integrated firms interact with differences in the long term efficiency of the two forms. However, we neglect the strategic interactions that Farrell *et al.* model. In their model, firms are Bertrand competitors so that price (and profits) depend only on the cost of the second most efficient producer (they also show that their results extend to Cournot competition as well). Thus, the increase in efficiency due to specialization is more than outweighed by the increase in the "toughness of competition" when the number of competitors is large. In our

[4]This industry came into existence in 1956 with the invention of the disk drives at IBM. Initially, IBM developed and designed the disk drives itself, while employing vendors for the manufacturing process. In time, the existence of a large vendor base allowed entry for competitors (Such as Storage Technology (STC), Memorex, Control Data (CDC), Univac and Burroughs) in the design & development process. In an effort to cut off the supply of components to its competitors, by 1963, IBM had brought the manufacturing activity in-house, setting off a vertical integration trend in the industry (Christensen [1995]). Christensen cites an internal IBM document to also point out that this trend coincided with a much broder trend of vertical integration in the industry associated with the launch of IBM's mainfraim System/360. By 1978 this trend had reversed. The leading firms started moving away from vertical integration and towards specialization (For more details of the industry's history see Christensen [1995]). While the transaction cost literature has typically viewed these developments in terms of the internal capabilities of the firms, the changing "make - buy" may instead be optimal responses to changing industry structure, especially of suppliers of components.

model, market price depends on the supply curves of all existing producers, and hence, upon the average efficiency of all producers.[5] Also, we assume increasing marginal costs, while Farrell *et al.* assume constant marginal costs.

In the next section we set out a simple model of a competitive market and briefly discuss its steady state. Section 3 reports on the dynamic properties of the model that we explore through numerical simulations. We provide intuition for these properties in section 4 by analytically describing the properties of the entry and exit process. In section 5 we endogenise transaction costs as a function of the number of transactions. Our simulations highlight the interactions when both extent of specialization and transaction costs are endogenous. Section 6 summarizes our results and concludes the paper.

II The Model

We model a competitive market with both vertically integrated and specialized firms. We assume that the final product I consists of two components, H and S. One unit each of H and S are needed to produce one unit of I. A firm can either integrate the production of both components in-house or it may specialize in the production of either of the two components. We assume that due to incompatibility in design, integrated firms do not buy from or sell to other firms.[6] H-type firms buy component S from S-type firms at price p_s and compete in the final good market with integrated producers, where the market price is p_q. The demand for the final product is given by

[1] $$D(p_q) = a + b p_q.$$

Costs are assumed to be quadratic in output so that, using subscripts s, h and i to refer to S-type, H-type and I-type (integrated) firms respectively, we write the cost function as

[2a] $$C_s(q_s, \theta_s) = \alpha + (q_s^2 + q_s)\,\theta_s + \tau$$

[2b] $$C_h(q_h, \theta_i, p_s) = \beta + (q_h^2 + q_h)\theta_h + q_h p_s + \tau$$

where α and β are the fixed costs, θ_s and θ_h are (in)efficiency parameters, and τ represents the transaction costs due to specialization. We assume that θ_s and θ_h are *iid* random variables, distributed uniformly over [1, 2], that each firm draws upon entry into the industry, but after entry, are fixed for the life of the firm. To make costs symmetric, the cost function for an integrated firm is simply the sum of the costs of producing S and H plus a cost of coordinating activities within the firm γ, minus the transaction costs 2τ. Using [2] and the requirement that the integrated firm produces equal amounts of S and H, an integrated firms cost function can be written as

[3] $$\begin{aligned} C_i(q_i, \theta_h, \theta_s) &= C_h(\cdot) + C_s(\cdot) \Leftrightarrow q_i\, p_s \Leftrightarrow (2\,\tau \Leftrightarrow \gamma) \\ &= \alpha + \beta + (q_i^2 + q_i)\,\theta_i + \gamma \end{aligned}$$

where $\theta_i = \theta_h + \theta_s$.

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[5]However, the entry process in our model does depend on the properties of the tails of the distribution of costs. Also, Farrell *et al.* show that their results extend to Cournot competition as well.

[6]In terms of the standards literature, each integrated firm produces to a closed proprietary standard, while the specialized firms produce to a common and closed standard as well.

II i Market Behavior. Firms are price takers, and set output by equating marginal cost to the market price. This gives

$$q_i = (1/2)\left(\frac{p_q}{\theta_i} \Leftrightarrow 1\right)$$

$$q_h = (1/2)\left(\frac{p_q \Leftrightarrow p_s}{\theta_h} \Leftrightarrow 1\right)$$

[4a,b,c]

$$q_s = (1/2)\left(\frac{p_s}{\theta_s} \Leftrightarrow 1\right).$$

Prices are determined by the market clearing conditions

$$\sum_i^n q_i + \sum_h^m q_h = a + b\,p_q$$

[5a,b]

$$\sum_h^m q_h = \sum_s^k q_s$$

where n, m and k are the number of I-type, H-type and S-type firms respectively at any given time. (We suppress all time subscripts for convenience of exposition). Note that since transaction and coordination costs are internal to firms, arbitrage implies that price for the h good, p_h, is simply $p_q \Leftrightarrow p_s$. The latter are given by

$$p_q = \frac{2a + (m+n) + \left(p_s\right)\cdot\left(\sum_h^m (1/\theta_h)\right)}{\sum_i^n (1/\theta_i) + \sum_h^m (1/\theta_h) \Leftrightarrow 2\text{b}}$$

[6a,b]

$$p_s = \frac{\left(p_q\right)\cdot\left(\sum_h^m (1/\theta_h)\right) + (k \Leftrightarrow m)}{\sum_s^k (1/\theta_s) + \sum_h^m (1/\theta_h)}\ .$$

II ii Entry and Exit. Following Jovanovic [1982], we assume "noisy" selection, where low cost firms survive and high cost firms exit.[7] Potential entrants choose whether to enter and their type (I-type, H-type or S-type), based on the current market prices and their own efficiency parameters θ_s and θ_h. Post entry, costs do not change (no learning), and if it becomes unprofitable to continue producing as a particular type over time, we assume that a firm exits the industry rather than switch its organizational form.[8]

We assume that at most one firm can enter in a given period. A potential entrant draws two random values, θ_h and θ_s. The potential entrant looks at only the *current* prices and chooses whether to enter, and if so, as an S, H, or I type producer based on which form would earn the highest profit. Similarly, incumbents who realize negative profits exit, with the firm realizing the least profit exiting first. After the exit, the remaining firms evaluate their profits at the changed prices, as defined by [6a,b] above, and if profits for some firms are still negative, the firm

[7]Following Jovanovic [1982] the model allows firms to differ in output due to differences in efficiency rather than in fixity of capital. However, following Porter [1980] & Klepper [1996], the efficiency parameter of firms is a random variable with a uniform and continuous distribution.

[8]Ohanian [1994] in her study of the U.S. Pulp and Paper Industry between 1900-1940, found that few mills switched between integration and specialization once established. Once again, permitting such switches amounts to allowing a different type of entry. Allowing integrated firms to close unprofitable businesses would only enhance the prospects for specialization.

with the lowest profits exits. This process is repeated until all incumbents have non-negative profits. The last exit after each entry marks the end of a period. Note that in our model, exit takes place sequentially, with prices recomputed after each exit.

The assumption of myopic decision making – firms focus only on current period profitability in making their decisions – simplifies our analysis. However, given the uncertainty in the environment and the possibility of multiple equilibrium paths, making fully forward looking decisions is costly. Moreover, myopic decision making is almost rational, due to assumptions already made in the model: firms are price takers, there is no "learning", and sunk costs are absent. Introducing forward looking behavior will not effect the output decision since there is no learning and no strategic behavior. There is possible option value to entering the market (or staying in) even if currently unprofitable because prices may increase in the future.[9] Calculating the value of such a real option is difficult to say the least, and we ignore the option value of entering or remaining in the market. Note however that but for the jumps caused by the lumpiness of entry and exit (the number of firms is an integer), prices would never rise over time (since there is no demand uncertainty). Thus, if current profits are negative, then future profits would also be negative, implying an option value of zero. Forward looking behavior could conceivably affect the decision on the form of entry but the direction of the effect is unclear.

Note that we do not allow a potential entrant to simultaneously enter as both an H and S type. Although unrealistic, this assumption is made largely for expository purposes. To anticipate our results below, we find that the dynamics of the industry evolution favor specialization even when integration is more efficient in the long run (*i.e., when* $\gamma \Leftrightarrow 2\tau > 0$). Allowing the entry of two specialized firms in a period would automatically decrease the value of the measure of the degree of vertical integration that we use. Allowing the entry of two specialized firms in one period could lead to the reader to believe incorrectly that assumption to be the key factor driving our results, potentially obscuring the more fundamental effects we wish to highlight.[10]

II iii Long Run Industry Structure. In the stationary state, i.e., when opportunities for profitable entry have vanished, free entry implies that the industry structure – the organizational form of the firms in the industry – is determined entirely by the difference in the minimum average cost between the two organizational forms. (See figure 1 below.) If the cost of coordinating activities within firms (γ) is less than the cost of transacting over markets (2τ) the industry will be completely vertically integrated.[11] When $\gamma \Leftrightarrow 2\tau = 0$, the long run structure of the

[9]Prices may rise briefly because of the interaction effects. For instance, the entry of an H-type will raise p_s. Similarly, exit by an S-type may trigger exit by an H-type, which may trigger further exit by an S-type. In principle, this feedback effect could cause large scale exit and large jumps in price as well. However, we did not observe such outcomes in the three thousand odd simulations that we ran.

[10]Further, as we show below (lemma 1), for modest differences in long run efficiency, allowing a potential entrant to enter as two specialized firms would imply that no integrated entry would ever take place for some price range.

[11]The reverse is true unless the industry starts out vertically integrated. In the latter case, the industry will remain integrated even if γ - $2\tau < 0$, simply because we do not allow an S and H type firm to enter together.

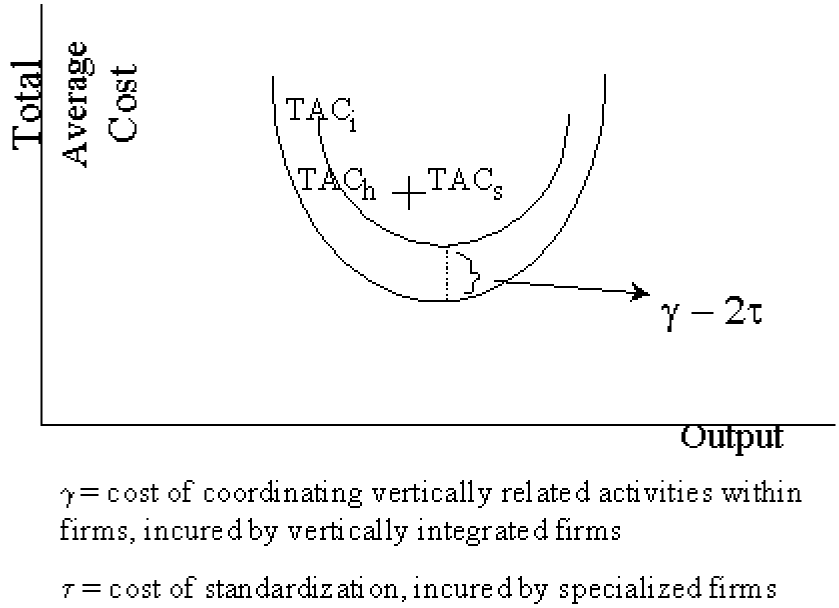

FIGURE 1. Long run Equilibrium

industry is indeterminate. Put differently, the long run industry structure is simply the structure that has lower costs – in our terminology, the efficient structure. Thus, vertical integration is efficient when $\gamma \Leftrightarrow 2\tau < 0$.

III Dynamics of Evolution

Though a stationary-state analysis is useful in understanding the effect of certain factors, it obscures interesting aspects of the dynamics of industry evolution. In particular, it obscures the role of differences in the distribution of capabilities (efficiency parameters) as well as of any interdependencies in decisions. We explored how these factors affect the convergence of the industry to its long run structure through numerical simulations.

In the first phase of simulations, τ was fixed and simulations were studied for different values of $\gamma \Leftrightarrow 2\tau$, where $\gamma \Leftrightarrow 2\tau$ ranges from $\Leftrightarrow 2\tau$ to $+2\tau$. Each simulation lasted for 500 periods. We ran 35 simulations for each value of $\gamma \Leftrightarrow 2\tau$, with equal numbers of H and S type firms but with different initial values of vertical integration (i) ($VI_0 \simeq 0.9$), (ii) intermediate ($VI_0 \simeq 0.5$) and, (iii) low ($VI_0 \simeq 0.2$), where the degree of vertical integration, VI, of the industry is defined as

$$\mathrm{VI} \equiv \frac{\sum_i^n q_i}{\sum_i^n q_i + \sum_h^m q_h}.$$

The parameter values used in the simulations are given in Appendix 1. These values imply that fixed costs are about 33% of the total long run costs. The range of values for $\gamma \Leftrightarrow 2\tau$ over which the simulations are run are equivalent to about 40% of the total fixed costs.

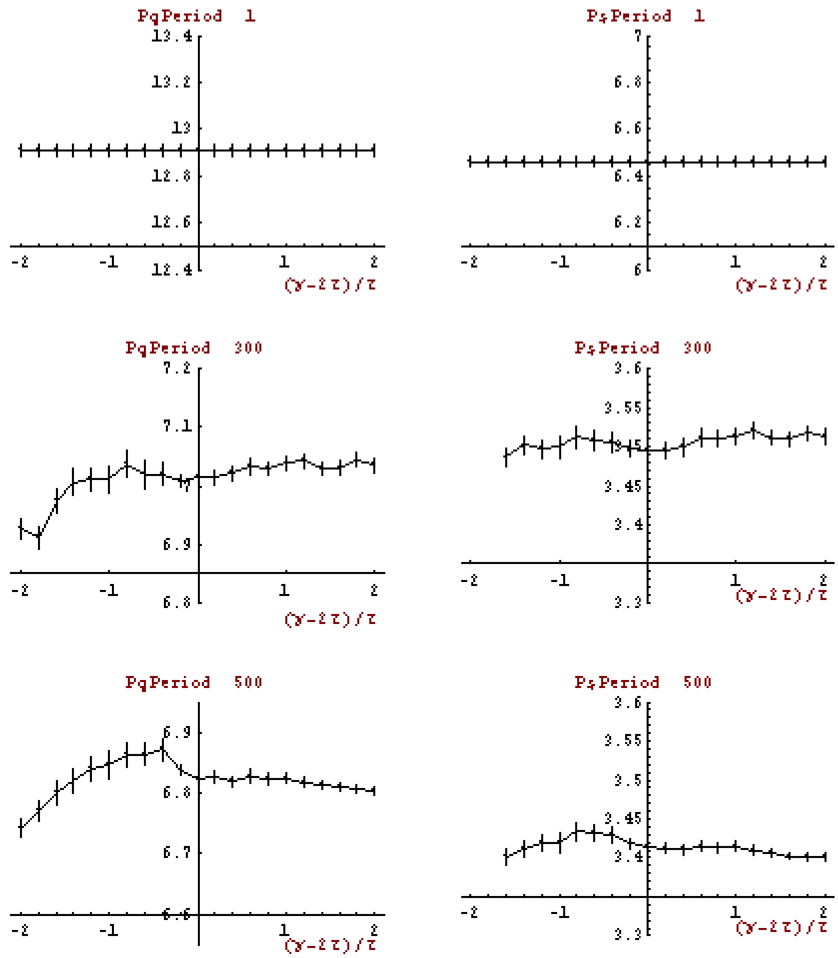

FIGURE 2. Snapshot of Mean Prices, P_q & P_s

III i Simulation Results: Transaction Costs Exogenous. Figures 2-5 present the simulation results. Briefly, they show that convergence to the long run equilibrium tends to be slow. They also show that the dynamic evolution of the industry is asymmetric with respect to the efficient industry structure. When vertical integration is the least cost long run structure (i.e., $\gamma \Leftrightarrow 2\tau < 0$), convergence is slow and uneven, particularly when $\gamma \Leftrightarrow 2\tau$ is small.

Figure 2 shows p_q and p_s at time periods 1, 300 and 500. The values shown are the average over the 35 simulations for the given value of $\gamma \Leftrightarrow 2\tau$, with the bars indicating the standard deviation around the average.[12] Over time, prices fall.

[12]We ran 35 simulations for each value of $\gamma - 2\tau$. All in all, we ran over 2000 simulations (including those with slightly different versions of the model, with very similar results). A more complete discription of simulation design and algorithm is given in appendix I. Further note that in all the figures, the error bars represnt the standard error and not standard deviation. Our simulations showed that 35 runs per value of $\gamma - 2\tau$ were enough in the sense that they gave us the asymptotic distrbutions, so that running further simulations will not be of much use is giving

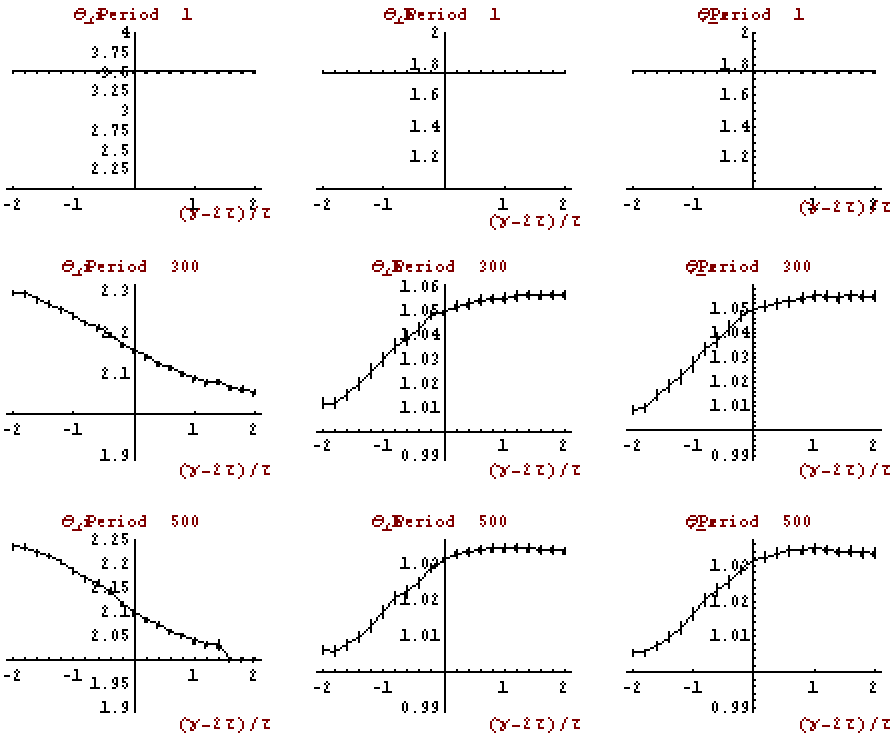

FIGURE 3. Snapshot of Mean θ_i, θ_h and θ_s

However, comparing across different values of $\gamma \Leftrightarrow 2\tau$, prices in the 500^{th} period tend to be somewhat higher when $\gamma \Leftrightarrow 2\tau$ is small. This is partly because variables take longer to reach their steady state values when neither organizational form is markedly more efficient. But there is more to the story because the effect is not symmetric: Prices are noticeably higher in the 500^{th} period when integration is the least cost organizational form.

The asymmetry is corroborated by figure 3 which shows that the average value of θ_s and θ_h for the S and H type firms (in the 500^{th} period) is lower, the lower is $\gamma \Leftrightarrow 2\tau$ when integration is more efficient but remains largely constant for $\gamma \Leftrightarrow 2\tau$ positive. By contrast, the average θ_i for the I-type firms is higher the lower is $\gamma \Leftrightarrow 2\tau$.

Both of these asymmetries are also reflected in figure 4 which shows the evolution of the industry structure. In essence, when specialization is the efficient long run organizational form ($\gamma \Leftrightarrow 2\tau > 0$), the industry structure rapidly converges to specialization, and increases in the extent of the cost difference, $\gamma \Leftrightarrow 2\tau$, do not have an appreciable effect beyond a point. By contrast, when integration is efficient, as long as $\gamma \Leftrightarrow 2\tau$ is small, the industry structure continues to be mixed: Specialized firms are likely to have a substantial market share, which decreases as the extent of

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us tighter estimates of the standard deviation of the mean. As a check, we ran 35 additional simulations for a selected value of $\gamma - 2\tau$. Not only did the mean and the standard deviation remain substantially unchanged (differences were of the order of 1-2%), the entire distrbution did not change by much. As expected, the standard error of the mean fell with the square root of N.

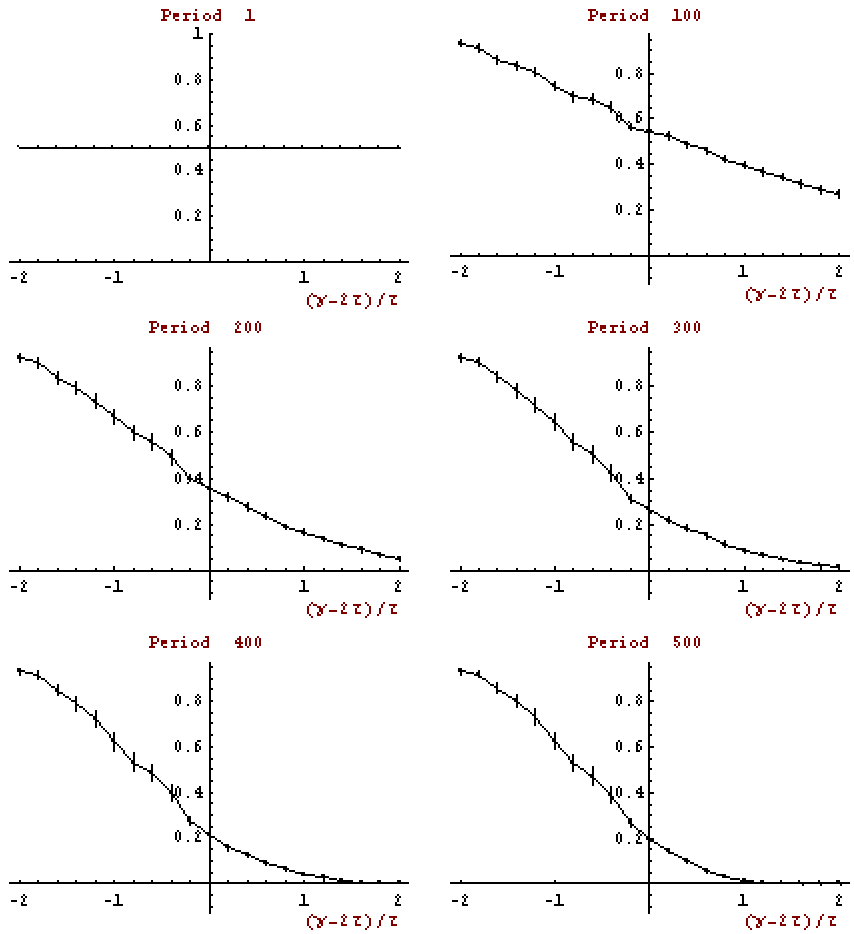

FIGURE 4. Snapshot of Mean VI, For Exogenious τ

cost advantage to integration increases. In particular, when both forms are equally efficient, the average degree of vertical integration in the industry is only about 20%, well below the 50% that one might expect based on steady state analysis alone. Notice also that the standard errors for the I-type firms tend to be larger when $\gamma \Leftrightarrow 2\tau$ is negative than for corresponding positive values of $\gamma \Leftrightarrow 2\tau$.

Figure 5 shows some *typical* time paths of VI for different values $\gamma \Leftrightarrow 2\tau$. The figure shows that when $\gamma \Leftrightarrow 2\tau$ is negative but small, VI actually moves away from its steady state value of 1, at least for the duration of the simulation. However, when $\gamma \Leftrightarrow 2\tau \ll 0$, VI evolves towards its steady state value of 1. By contrast, for $\gamma \Leftrightarrow 2\tau > 0$, VI almost always tends towards zero.

Our simulations revealed two further patterns. First, as figure 5 shows, very early in the history of the industry integrated entry is more likely than specialized entry. This recalls a prediction by Stigler (1951) that vertical integration is more likely early in the industry life-cycle because a new industry is likely to have to produce its inputs itself. As discussed below, in our model, integrated entry early

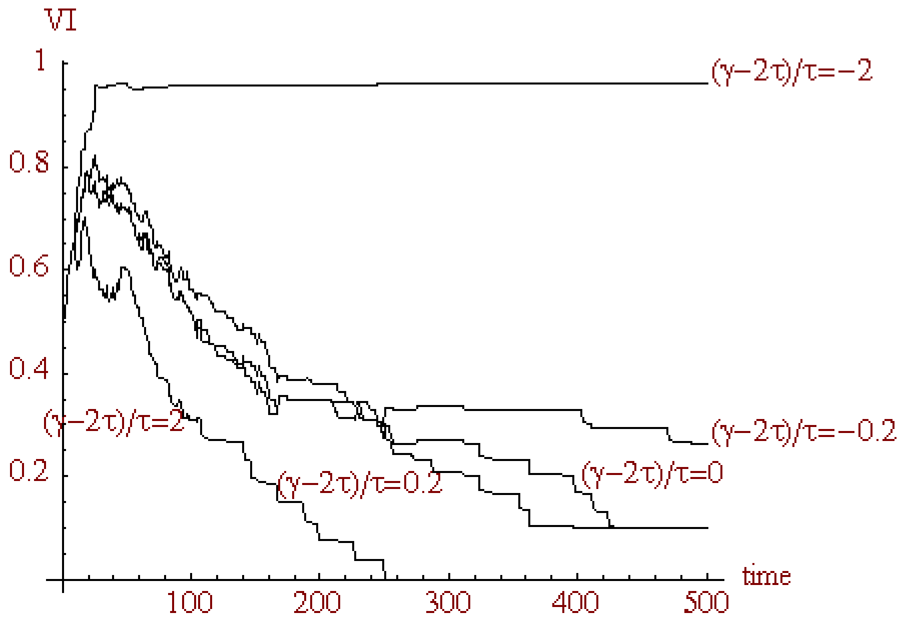

FIGURE 5. Typical Time Plots for Vertical Integration, Tau is Exogenious

TABLE 1. VI Statistics for Period 500, Exogenous τ, and $\gamma \Leftrightarrow 2\tau = 0$

	Low Initial VI	**Medium Initial VI**	**High Initial VI**
Mean	0.192190	0.194740	0.264200
$\boldsymbol{\sigma/\sqrt{n}}$	0.012931	0.013354	0.038930
Max	0.370440	0.368300	0.959650
Min	0.068227	0.068192	0.068207

where $\sigma/\sqrt{n}$ is the standard deviation of the mean

in the industry life cycle is taking place for a very different reason - prices are higher early in the life cycle and fall over time. We explain below in section IV why lower prices should favor specialized entry. The simulations also show that outcomes are sensitive to initial conditions. Table 1 shows that when both organizational forms are equally efficient in the long run, starting with high levels of vertical integration implies that the expected level of vertical integration is higher, and the difference is statistically significant.

To sum up, simulations with exogenous transaction and coordination costs have three features that need to be explained. (1) The dynamic processes are asymmetric. Convergence is slower and more uneven when integration rather than specialization is the steady state. Put differently, chance seems to favor specialization. (2) Integrated entry is more likely than specialized industry early in the industry life cycle but the odds of integrated entry appear to fall over time. (3) All else held equal, if the industry starts out as vertically integrated, the expected level of vertical integration is higher

IV Explaining the dynamics

What accounts for the specific patterns of industry evolution that the simulation results reveal? In this section we provide the intuition by examining the properties of the entry and exit process implied by our model. We begin by formalizing the division of labor effect (lemma 1) and the Babbage effect (lemma 2), which point to advantages of specialization as compared with the integrated form. The complex interactions between price levels and the transaction and coordination costs imply that we can only partially characterize the conditions under which specialized entry is more likely than integrated entry in proposition 1. However, a potential entrant may choose integration because a key private benefit of integration is that it allows a firm to profit from two activities rather than only one (proposition 2). Proposition 3 clarifies how final outcomes are sensitive to initial conditions.

Division of labor effect: Differences in θ_h and θ_s along with the assumption of increasing marginal costs implies that an integrated firm cannot take full advantage of its greater efficiency in one activity. As an illustration, let $\theta_{\mathrm{s}} = 1$ and $\theta_h = 2$, and $\mathrm{p}_q = 12$, $p_s = 6$, so that $\mathrm{p}_h = 6$ as well. Then the profit maximizing quantities for the S and H firms are 2.5 and 1 respectively, and their marginal costs are 6 and 6. An integrated firm has to produce the two components in fixed proportions. Thus, it will produce 1.5 units, with a marginal cost of 4 in the s activity and a marginal cost of 8 in the h activity. This implies that it underproduces s and overproduces h.

Lemma 1 (Division of Labor Effect). *Let $\Pi^j(\theta_j)$ be the maximized profits of j type firm, $j = i, s, h$. Then $\gamma \Leftrightarrow 2\tau = 0$ implies that $\Pi^i(\theta_h + \theta_s) < \Pi^s(\theta_s) + \Pi^h(\theta_h)$ if $\frac{\theta_h}{\theta_s} \neq \frac{p_q - p_s}{p_s}$, and $\Pi^i(\theta_h + \theta_s) = \Pi^s(\theta_s) + \Pi^h(\theta_h)$ otherwise.*

Proof. One can write $\Pi^i(\theta_h + \theta_s) = \Pi^s(\theta_s, \mathrm{q}(\theta_i)) + \Pi^h(\theta_h, \mathrm{q}(\theta_i)) + (\gamma \Leftrightarrow 2\tau)$, where $\Pi^s(\theta_s, \mathrm{q}(\theta_i))$ are the profits of the s type when it produces quantity $\mathrm{q}(\theta_i)$. By definition, $\Pi^s(\theta_s, \mathrm{q}(\theta_i)) \leq \Pi^s(\theta_s)$. Further, the inequality is strict whenever $\frac{\theta_h}{\theta_s} \neq \frac{p_q - p_s}{p_s}$. By a similar argument, $\Pi^h(\theta_h, \mathrm{q}(\theta_i)) < \Pi^h(\theta_h)$. The result follows directly.[13] □

Lemma 1 implies that entry requirements for integrated entry are more stringent. Let θ_i^* represents the largest value of θ_i such that the profits, $\Pi^i(\theta_i^*)$, are non-negative, and θ_s^* and $\theta_h^*$are similarly defined for S and H types respectively. Note that θ_s^* and θ_h^* are increasing in prices and decreasing in transaction costs and analogously for θ_i^* (see appendix 2). Entry as j type requires $\theta_j < \theta_j^*$. An incumbent with $\theta_j < \theta_j^*$ would have to exit. Thus, lemma 1 implies the following:

Corollary 1. *$\theta_h = \theta_h^*$ and $\theta_s = \theta_s^*$ implies $\Pi^i(\theta_i) < 0$, and hence, $\theta_i^* < \theta_s^* + \theta_h^*$.*

This corollary implies that for any given set of prices, the range of values for which integrated firms can enter or survive in the market is smaller than for specialized firms. Note that since the inequalities are strict, the results will continue to hold even when $\gamma \Leftrightarrow 2\tau$ is negative but small enough. Formally we have,

Corollary 2. *Given θ_s^*, $\theta_h^* > 1$, there exists $\epsilon > 0$ such that when $\|\gamma \Leftrightarrow 2\tau\| < \epsilon$ then $\theta_i^* < \theta_s^* + \theta_h^*$.*

Babbage Effect: There is a second effect favoring specialization, which arises from the assumption that the parameters θ_h and θ_s are independently distributed.

[13] When $\frac{\theta_h}{\theta_s} = \frac{p_q - p_s}{p_s}$, $q_s = q_h = q_i$, so that $\Pi^s(\theta_s, \mathrm{q}(\theta_i)) = \Pi^s(\theta_s)$.

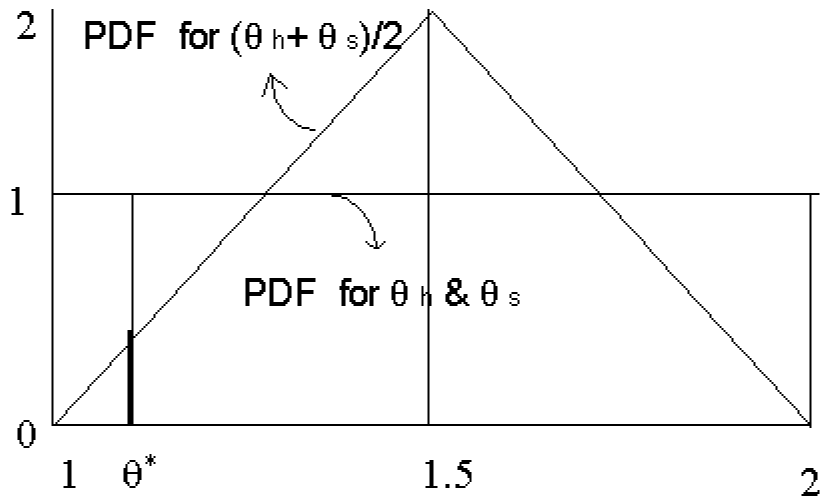

FIGURE 6. Distribution of $\theta_i/2$, θ_h, and θ_s. The "Babbage Effect"

An integrated firm's efficiency parameter, θ_i, is the sum of $\theta_h$and $\theta_s$that the firm draws. This implies that for any $x_s, x_h \in [1,2]$, $Pr(\theta_i < x_s + x_h) < Pr(\theta_s < x_s) + Pr(\theta_h < x_h)$. In other words, a potential entrant is more likely to be efficient at one of the activities rather than be good enough on average at both. The assumption that θ_h and θ_s are identically distributed also implies that the probability distribution of θ_i is more strongly clustered around the mean than the original distribution. This follows because $\frac{\theta_i}{2}$ is the average of two independent random variables. In particular, when the distribution of θ_s, $g(t)$ is uniform over $[1,2]$, the probability distribution, $f(t)$ of $\theta_i/2$ is given by

$$f(t)\,for\,\frac{\theta_i}{2} = \begin{cases} t \Leftrightarrow 1 & for\, t < 1.5 \\ 2 \Leftrightarrow t & for\, t > 1.5 \end{cases}$$

as shown in figure 6 below. Formally we have the following result:

Lemma 2 (Babbage Effect)**.** *Let F and G represent the distribution functions for $(\theta_i)/2$ and θ_s. Then F second order stochastically dominates G.*

Proof. The proof readily follows by noting that for any concave function $U(\theta)$, $U\left(\frac{\theta_s+\theta_h}{2}\right) > \frac{1}{2}U(\theta_s)+\frac{1}{2}U(\theta_h)$, from which it follows that $EU\left(\frac{\theta_s+\theta_h}{2}\right) > \frac{1}{2}EU(\theta_s)+\frac{1}{2}EU(\theta_h) = EU(\theta_h)$ where the last equality follows because θ_s and θ_h are *iid* variables. (See Rothschild and Stiglitz [1970] for further details.) □

Corollary 3. *There exists $\hat{x} \in (1,2)$ such that $Pr\{\theta_h + \theta_s < 2x\} < Pr\{\theta_h < x\} = Pr\{\theta_s < x\}$ for all $x < \hat{x}$.*

The proof follows directly by noting that lemma 2 implies that F crosses G from below. Combining with the corollaries to lemma 1, the corollary to lemma 2 highlights the implications of the Babbage effect. It suggests that when prices are sufficiently low (so that the entry requires a very low value of θ) the necessary conditions for integrated entry are less likely to be satisfied than for entry by S and

H types. Proposition 1 formalizes this intuition for the case where $p_q = 2p_s$ so that the entry thresholds are the same for the S and H types.

Proposition 1. *For $p_q = 2p_s$, there exist $p_q^* > 0$ & $\epsilon(p_q^*) > 0$, such that if $\|\gamma \Leftrightarrow 2\tau\| < \epsilon(p_q^*)$ & $p_q \in [p_q^0, p_q^*]$ then $Pr\{\theta_i < \theta_i^*\} \leq Pr\{\theta_h < \theta_h^*\} = Pr\{\theta_s < \theta_s^*\}$, where $p_q > p_q^0$ implies that $\theta_j^* > 1, j = s, h$.*

Proof. Note first that $p_q = 2p_s$ implies that $\theta_h^* = \theta_s^*$. Further, given p_q^*, by lemma 1, we can always find an ϵ such that $\|\gamma \Leftrightarrow 2\tau\| < \epsilon(p_q^*)$ implies that $\theta_i^* < \theta_h^* + \theta_s^*$. By lemma 2, $Pr\{\theta_i < \theta_i^*\} \leq Pr\{\theta_h < \theta_h^*\} = Pr\{\theta_s < \theta_s^*\}$. Finally, as p_q and p_s decrease, so do θ_h^* and θ_s^* so that lemma 2 still applies, as long as p_q and p_s are high enough to permit specialized entry.[14] □

Proposition 1 clarifies the source of the asymmetry in the convergence to long run equilibrium between the cases when integration is efficient and when specialization is efficient. As long as coordination costs are not much larger than transaction costs and potential entrants are not at their maximal efficiency ($\theta_h, \theta_s < 1$), specialization is advantageous. When prices are low and entry conditions are stringent, specialized entry is more likely than integrated entry. However, a potential entrant may choose integration if prices are high enough to enable it to earn rents from both types of activities. A potential entrant will enter as an integrated firm if $\Pi^i(\theta_h + \theta_s) > Max\{\Pi^s(\theta_s), \Pi^h(\theta_h), 0\}$, with analogous expressions for entry as S and H type.

Proposition 2. *If $p_s > 2$ & $p_q = 2p_s$, then $\left.\frac{\partial(\Pi^i(\theta_i) - \Pi^k(\theta_k))}{\partial p_s}\right|_{p_q = 2p_s} > 0, k = s, h$. Further, for $\gamma \Leftrightarrow 2\tau = 0$ and p_s and p_q large enough, $\Pi^i(\theta_i) \Leftrightarrow \Pi^k(\theta_k) > 0$, $k = s, h$.*

Proof. Observe that $\Pi^i(\theta_i) = \frac{(p_i - \theta_i)^2}{4\theta_i} \Leftrightarrow (\alpha + \beta) \Leftrightarrow \gamma$, and analogously for specialized firms. Hence, one can verify by direct calculation that $p_q = 16$, $p_s = 8$ implies that $\Pi^i(\theta_i) \Leftrightarrow \Pi^j(\theta_j) > 0$, for $j = s, h$. Next, observe that $\left.\frac{\partial(\Pi^i(\theta_i) - \Pi^s(\theta_s))}{\partial p_s}\right|_{p_q = 2p_s}$ can be written as $\theta_s\{(p_s \Leftrightarrow \theta_s) + (2p_s \Leftrightarrow \theta_h)\}$ which is positive for $p_s > 2$. Thus, $\Pi^i(\theta_i) \Leftrightarrow \Pi^j(\theta_j) > 0$, $j = s, h$ must hold for all higher price levels as well. □

Proposition 2 shows that when the market is profitable, as it is early in the industry life cycle, integrated entry is likely, even with $\gamma \Leftrightarrow 2\tau$ positive. A fall in prices over time lower the probability of entry of all types of firms, but propositions 1 and 2 suggest that the probability of integrated entry falls relative to that for specialized entry. We confirm this intuition numerically by showing that the relative odds of integrated entry fall with prices. Figure 7, which is drawn for a symmetric path with $p_q = 2p_s$, shows that for high prices, the conditional probability of integrated entry is high and drops as prices drop. The larger the value of $\gamma \Leftrightarrow 2\tau$, the greater the conditional probability of integrated entry for any given price. When the advantage to integration is only modest, the conditional probability can drop below 0.5 implying that "balanced" specialized entry (a specialized firm followed by a complementary type in the next period) is more likely than integrated entry. However, when integration is the efficient form in the long run, eventually prices fall enough to choke off specialized entry while still leaving

[14] Note that if p_q drops below p_q^0, lemma 1 ceases to apply because θ_s^*, θ_h^* drop below 1.

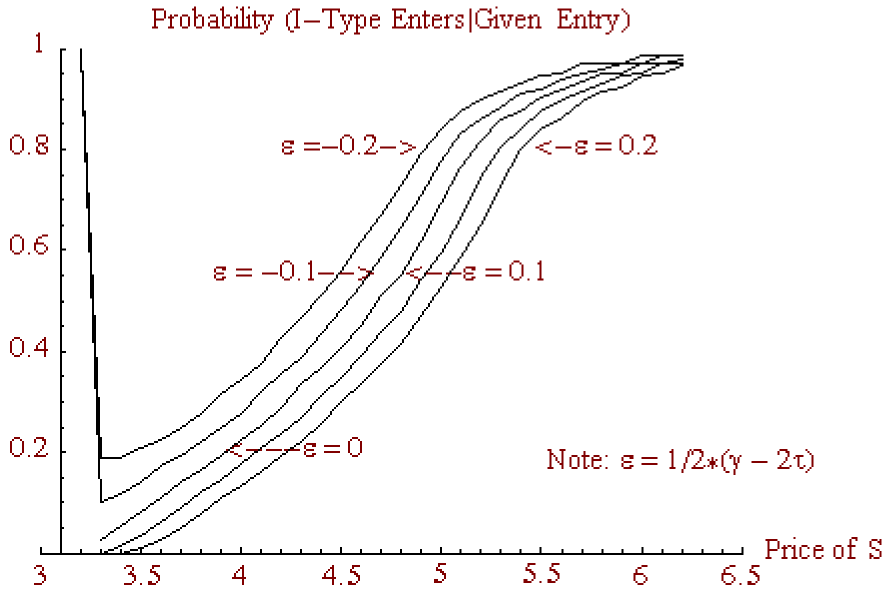

FIGURE 7. Probability (I-Type Enters|Given Entry)

room for integrated entry. At this point, the conditional probability of integrated entry increases sharply.

We next show that the evolutionary dynamics are not neutral to the type of entry that takes place. Proposition 3 below shows that "balanced" specialized entry tends to lower all prices by a greater amount than an entry by an I-type firm. In order to do so, we first state and prove (in lemma 3) a result about the expected values of the inverse of efficiency parameters.

Lemma 3. *$E(\frac{2}{\theta_s+\theta_h}|\,\theta_s < x, \theta_h < x) < E(\frac{1}{\theta_h}|\,\theta_h < x) = E(\frac{1}{\theta_s}|\,\theta_s < x)$ for all $x \in (1,2]$.*

Proof. Let the conditional distribution function for θ_s and θ_h be $\widetilde{G}$ and let $\widetilde{F}$ be the corresponding conditional distribution function for $\frac{\theta_s+\theta_h}{2}$ and finally let $\widetilde{g}$ and $\widetilde{f}$ be the corresponding density functions. If g is uniform over $[1,2]$ then $\widetilde{g}$ is uniform over $[1,x]$. By earlier reasoning, it follows that $\widetilde{F}$ second order stochastically dominates $\widetilde{G}$. If so, the expected value of any convex function, such as the inverse, is higher for $\widetilde{G}$ than for $\widetilde{F}$. □

Lemma 3 suggests that with equal numbers of specialized firms "balanced" entry should lower both p_q and $p_{\mathrm{h}} \equiv p_q \Leftrightarrow p_s$ by a greater amount than integrated entry if the entrants have the average efficiency of incumbents. More precisely, if the industry starts with one fewer integrated firm and one additional S and H type firm, both sets of prices are likely to be lower. Formally we have the following proposition.

Proposition 3. *Let m be the initial number of S and H type firms, and n the number of I type firms. Let $\phi_s = \frac{1}{m}\sum_s^m(\frac{1}{\theta_s})$, and likewise for ϕ_h and ϕ_i. Then* *holding ϕ_j constant,*

$$E\Big(\frac{dp_q}{dm}\Big)\Big|_{dm-dn=0} < 0,\; E\Big(\frac{dp_s}{dm}\Big)\Big|_{dm-dn=0} < 0,\; E\Big(\frac{dp_h}{dm}\Big)\Big|_{dm-dn=0} < 0.$$

Proof. Note first that when there are an equal number of S and H type firms, p_h and p_s are linearly related. Thus, if one increases, the other will increase as well. Further, from 6a and 6b, note that

$$Sign\Big(\frac{dp_q}{dm}\Big)\Big|_{dm-dn=0} = Sign\Big(\frac{dp_s}{dm}\Big)\Big|_{dm-dn=0} = Sign[(\phi_s + \phi_h)\phi_i \Leftrightarrow \phi_h\phi_s].$$

Taking expectations and using the fact that θ_s and θ_h are *iid* variables, and hence, so are ϕ_s and ϕ_h, it follows that $Sign\mathrm{E}\Big(\frac{dp_q}{dm}\Big)\Big|_{dm-dn=0} = Sign\mathrm{E}\Big(\phi_h(2\phi_i \Leftrightarrow \phi_s)\Big)$. Since each firm's draws are independent, it follows that

$$Sign\mathrm{E}\Big(\frac{dp_q}{dm}\Big)\Big|_{dm-dn=0} = Sign\, E\Big((2\phi_i \Leftrightarrow \phi_s)E(\phi_h)\Big)$$

which is negative by lemma 3 since $E(\phi_{\mathrm{h}})$ is positive.[15] □

Proposition 3 is consistent with the results that Farrell *et al.* [1998] obtain where industry costs (and prices) are always lower under specialization. Combined with proposition 2, it explains the time paths in figure 5 and the sensitivity to initial conditions. Proposition 3 shows that prices tend to be lower when the initial industry structure has a larger share of specialized firms. Lower prices, even as they decrease the absolute probability of entry, tend to increase the odds of specialized entry, by propositions 1 and 2. Thus, all else held constant, starting with a highly specialized industry may encourage further specialized entry.

These results imply that even when integration is the more efficient form, the industry structure does not necessarily converge monotonically to it, but instead can diverge away from it for sustained periods. This divergence is important because a variety of factors may prevent the industry structure from reaching the efficient state. For instance, suppose that firms have to incur a small cost in order to observe their efficiency parameters. Such information acquisition costs are neutral with respect to choice of entry type. Also, when expected profits are high, as they are in the initial stages of an industry, this cost is irrelevant and the industry will evolve as described above. However, over time as prices fall, the expected profit from entry may fall enough that entry stops altogether. It is then likely that the industry will retain a high degree of specialization even though there are advantages to integration.

V Endogenous Transaction Costs

As noted earlier, long run cost differences between the different organizational forms play a key role in the evolution of industry structure. We have modeled these differences as arising due to transaction costs. It seems reasonable to suppose that transaction costs would depend on the number of transactions. For one, as the number of transactions increase, intermediary firms and other institutions

[15] We are implicitly assuming that the incumbent firms in period zero have efficiency parameters that are drawn from the same conditional distribution. Thus, the proposition does not apply directly to time periods other than the initial period because the conditional distributions may differ across types.

Table 2. Probability of Vertical Integration

	Low Initial VI	**Medium Initial VI**	**HI Initial VI**
$\tau = \gamma \cdot VI$	$\frac{6}{35}$	$\frac{12}{35}$	$\frac{4}{5}$
$\tau = \gamma \Leftrightarrow \left(\gamma \sum_h^m q_h\right)/M$	$\frac{11}{35}$	$\frac{14}{35}$	$\frac{28}{35}$

(that we do not model explicitly) may arise to facilitate transactions. If the major transaction cost are due to imperfect compatibility and standardization, an increase in the number of transactions may lead to the development of *de facto* standards. Alternatively, industry associations or public policy may lead such a standardization effort. The fixed costs of such initiatives implies that they are not worthwhile unless the value and number of transactions is large.

To the extent that transaction costs are due to negotiation and contracting costs, an increase in the number of transactions may induce entry by efficient intermediary institutions, as well as the introduction of new transaction technologies. In turn, intermediaries can help standardize contracts, reduce search costs and improve the efficiency of transactions. We model this process by letting τ be a function of the number of "transactions". In our model, the number of transactions is equal to the output of specialized firms. For our numerical simulations, we used two different types of functional forms. In the first, transaction costs decreased linearly with the ratio of the output of the specialized firms to the total market output i.e. $\tau = \gamma \cdot$VI. In the second, τ decreased linearly with the ratio of the output of the specialized firms to the total potential market output, i.e., $\tau = \gamma \Leftrightarrow \left(\gamma \sum_h^m q_h\right)/M$ where M is the quantity demanded when price is equal to the long run average cost (i.e. the minimum average cost for $\theta_i = 2$). Both forms yield very similar results (see table 2) and in the discussion we will focus on the results for the first specification. Note also that long run costs are lower under specialization.

V i Results. How should the endogeneity of τ affect our earlier results? In essence, we have introduced a form of real industry level increasing returns to specialization (a type of network externality). As is well known, network externalities tend to produce multiple equilibria, and dynamics that are sensitive to initial conditions. So also in our model.

As table 1b shows, in our model, the industry moves either towards complete integration or complete specialization with very high probability. In other words, the movement towards a long run value is more rapid than in the case with exogenous τ. Further, initial conditions matter and so do small chance events early in the history. For instance, a high degree of initial vertical integration is likely to cause integration to increase further, and conversely, a low degree of vertical integration at the start tends to result in a specialized industry structure with a higher probability. There are two reasons. First, as we have already seen in propositions 2 & 3, a higher degree of integration implies somewhat higher prices on average, and therefore, higher odds of integrated (as compared with specialized) entry. Further, a high degree of vertical integration implies a large value of τ. Nonetheless, chance continues to play an important role as well. Even when the initial industry configuration is dominated by vertically integrated organizational form, there is about a 20% probability that the other organizational form will eventually dominate.

Although we do not show it here, we also simulated how the time paths are affected by a change in the number of firms and shifts in demand. With a given demand curve, starting with fewer firms amounts to starting with higher prices. As proposition 3 suggests, this favors integrated entry.[16] Integrated entry also increases τ, thereby hurting specialized firms, both incumbents and potential entrants. The latter effect, which is absent in the case with exogenous τ, implies that *when there are increasing returns to specialization, an industry is more, not less, likely to become integrated.* The reason is simple. Early in the history of the industry, higher prices favor integrated entry. However, by raising τ, integrated entry hurts incumbent and potential specialized firms. Through a feedback process, the industry moves towards complete integration. A similar reasoning suggests that increasing the intercept of the demand curve will also increase the probability that the industry will be (inefficiently) integrated in the long run: As the demand curve shifts out, the average price increases, thereby increasing the likelihood of integrated entry.

V ii Social Welfare Implications. With endogenous transaction costs a specialized industry configuration is always socially more efficient in our model. Transaction costs decline with the extent of specialization, so that a fully specialized industry configuration has a value of $\tau = 0$. However, as our simulations strongly suggest, vertical integration can be the long run equilibrium, particularly if the industry starts with a high degree of vertical integration.

Using the parameter values we use for the simulations, we can quantify the extent of long run welfare loss. In the long run, since price is equal to minimum average cost, producer surplus is zero. Thus, the change in welfare is equal to change in the consumer surplus. With complete specialization, the long run price of q is equal to 6, which, given the demand curve $P_q = 40 \Leftrightarrow q$, implies a consumer surplus of 578. With complete vertical integration, the long run price is equal to 6.6, which implies a consumer surplus of a little over 557. This implies that when the relevant fixed costs, γ and τ (average value), are about 7.5% of the average costs, the welfare loss from integration is about 3.6%.

As costs associated with the choice of organizational form increase in importance, so do the welfare losses. For instance, if γ were to double, the welfare losses would also approximately double to about 7.5%. Similarly, if we shift the demand curve to the right, the percentage of welfare losses decrease, although they increase in absolute levels. The intuition is that since long run prices are determined strictly by the long run average costs, an outward shift of the demand curve implies a decrease in the elasticity of demand. With a given price difference between the two organizational forms, this implies a lower *percentage* welfare loss. However, the shift in demand also implies a larger equilibrium quantity, and hence the absolute welfare loss is greater . For a similar reason, holding all else constant, if one doubles the fixed costs α and β, the welfare loss increases from 3.6% to about 4.14% but decrease in absolute amount.

[16]For instance, holding initial VI at 0.2, if the industry starts out with 10 integrated firm equivalents instead of 20 as in our reported simulations, the probability of vertical integration increases to about 53% from its reported level of 17%.

VI Summary and Conclusions

We develop a simple model of vertical integration and specialization in an industry. Specialization implies that one does not have to acquire competencies in all activities (Babbage effect). Furthermore, when such competencies are not perfectly matched, integrating the activities based on those activities imposes an additional cost (division of labor effect). These ideas have now gained currency under the more modern title of "core-competency". The other important element of our model is that that specialization and division of labor across firms involves trade, and therefore involves coordination of decisions. When these decisions are made by firms that enter and exit over time, the dynamic evolution of the system may be conditioned by its current state, and not simply by its long run equilibrium.

The dynamics displayed by our model supports this intuition. The Babbage effect and the division of labor effect tend to move the industry towards specialization When there integration is only slightly more long run efficient than specialization, the short term dynamics in favor of specialization counteracts the long run lower costs associated with integration, causing the industry to evolve away from its long run equilibrium, albeit temporarily. This transient divergence is nonetheless interesting because should further entry into an industry be stopped for any reason, the industry structure would look very different from its long run situation.

When we explicitly allow for industry level increasing returns to specialization by allowing the level of transaction costs to decline with the degree of specialization, the industry may not achieve its cost minimizing structure even in the long run. In our model, complete specialization is more efficient when transaction costs decline with the number of transactions. Nonetheless, depending on the initial conditions and on chance events early in the industry life cycle, specialization is only attained with probability that ranges from 20% to about 85%. It is likely, as in Farrell et al [1998], that these probabilities would be even lower if incumbent integrated firms can behave strategically to lower the share of specialized firms and raise the level of transaction costs.

Our results point to the limitations of the transaction cost perspective on the extent of the division of labor across firms. The transaction cost perspective is limited in two important respects. The first has to do with the number of sellers. Transaction cost based models recognize the "small number of suppliers" problem. What is obscured is that the (small) numbers of suppliers is likely to affect the number of actual and potential buyers, and vice versa Introducing explicit dynamics shows that the dynamic evolution of an industry is not simply governed by its steady state, but can diverge away from the steady state for sustained periods.

The second major limitation of the transaction cost model is the endogeneity of the level of the transaction costs. Transaction cost models correctly note that the level of transaction costs determine the number of market transactions. However, if the "thickness" of the market itself affects the cost of transacting over the market, then different long run structures of the industry are possible. If so, when industries are geographically limited, the structure of an industry may vary significantly across countries or regions. In other words, our model suggests that transactions costs themselves may be conditioned by industry structure. Or, to use Allyn Young's insightful conclusion reached nearly seventy years ago, the division of labor is limited by the division of labor

Appendix 1

Parameter values used in the simulations, $\alpha = \beta = 1$, $a = 40$, $b = \Leftrightarrow 1$. Starting number of firms = 20 integrated equivalents. A pair of H and S type firms is treated as equivalent to one integrated firm. For the endogenious τ case, the cost of coordianation, γ was set equal to 0.5.

Simulation Design. Simulations were run for exogenous and endogenous τ. For exogenous τ, we varied $(\gamma$ - $2\tau)/\tau$ between -2 and 2 incremented by 0.2. At the average values of τ and γ, the long run average cost are about 6.6, and the total cost per firm are about 7.36. This implies that the total fixed costs for the specialized form $= \alpha + \beta + 2\tau = 2.5$, or about 33% of the total cost. Thus our simulations imply that the fixed costs of the integrated form ranges between 2 and 3. Put differently, the variation is a little less than 15% of total cost.

For each value of $(\gamma$ - $2\tau)/\tau$, we ran thirty five simulations. All the variables and initial conditions were the same across each set of 35 simulations, except for the seed used to generate the random numbers *within* a simulation, which was different. Thus, a total of $35\times21 = 735$ simulations was run for exogenous τ with the initial number of firms chosen such that the initial degree of vertical integration was about 0.5. In addition, we also ran some simulations for the exogenous case with the initial conditions such that the vertical integration in the first period was about 0.2 or 0.8. For both low and high initial VI, $(\gamma$ - $2\tau)/\tau$ was set at -2, 0 and 2 (thus the additional simulations were, $35\times3 \times 2 = 210$).

For the endogenous case, we chose three types of initial conditions: (i) low initial VI, (ii) medium initial VI and, (iii) high initial VI. For each case, thirty five simulations were run and recorded. In addition, all three cases were also simulated using different specifications for the functional form to endogenise τ. The results were robust to the specification of the functional form. The total number of simulations for the endogenous case (per functional form) were $35\times3 = 105$.

All simulations were run for 500 periods (a period is defined in the paper). For each simulation, the value of twenty two variables was recorded at each period. In addition, we also kept track of the initial conditions and the value of the seed used to generate the random numbers. This helps us to regenerate any particular simulation. Finally, we repeated the simulation experiment for different values of the demand curve parameters.

Algorithm 1 (for Simulations). ***Period 1:***

• *Set initial number of firms of each type.*

• *Given the number of firms of each type, generate as many random numbers between appropriate ranges for the efficiency parameters.*

• *Use Equations[4a,b,c] to compute the output of each firm. If the output of any firm is negative, delete that firm.*

• *Given the parameters of the demand curve (slope and intercept) use equations [6a,b] to compute market prices.*

• *Given market prices, compute the profits of each firm. If firms have profits less than zero, then delete the firm with the most negative profit. Recompute prices and profits. Repeat, until all firms have non-negative profit. At this point, record the total outputs, number of firms of each type, prices, degree of vertical integration and other variables of interest, as the* ***first*** *period values.*

Period t:

•Generate two random numbers between 1 and 2.
•Given the prices at the end of the t ⇔1 period and the two random numbers generated, compute potential outputs and potential profits for H-type, S-type and I-type (where the potential profits for I-type are computed using the sum of the two random numbers just generated). An entry is marked (i.e., the number of firms of j-type increase by one) if the potential output is non-negative and the potential profit is maximum and non-negative.
•If entry takes place, recompute the prices (6a,b) outputs (4a,b) and profits of all existing firms.
•If firms have negative outputs or negative profits, they exit (i.e. are deleted) sequentially. The firm making the most negative profit exits first. Prices, outputs and profits of all remaining firms are recomputed. The process is repeated until none of the incumbents have negative outputs or profits. At this point, record the total outputs, prices, number of firms of each type, degree of vertical integration and other variables of interest, as the **t** period values.

Appendix 2

Characterizing Entry Conditions: The necessary entry condition is that the potential entrant draw an efficiency parameter such that with the given prices, p_q and p_s, it should earn non-negative profit. Using $\alpha = \beta = 1$, the threshold value for an I-type firm can be written as

$$\theta_i^* = p_q + 2(2+\gamma) \Leftrightarrow 2(2+\gamma)^{1/2}(p_q + 2 + \gamma)^{1/2}$$

The corresponding threshold values for H-type and S-type are

$$\theta_h^* = (p_q \Leftrightarrow p_s) + 2(1+\tau) \Leftrightarrow 2(1+\tau)^{1/2}(p_q \Leftrightarrow p_s + 1 + \tau)^{1/2}$$
$$\theta_s^* = p_s + 2(1+\tau) \Leftrightarrow 2(1+\tau)^{1/2}(p_s + 1 + \tau)^{1/2}$$

Sufficient conditions for entry as I-type are that
$\Pi^i(\theta_s+\theta_h) > Max\{\Pi^s(\theta_s), \Pi^h(\theta_h), 0\}$. Substituting # $\Pi^i(\theta_s+\theta_h) \Leftrightarrow \Pi^s(\theta_s) \Leftrightarrow \Pi^h(\theta_h) = \Leftrightarrow D$, where $D = \left(\frac{p_q^2}{\theta_i} + \frac{p_s^2}{\theta_s} + \frac{(p_q^2 - p_s^2)}{\theta_h}\right) > 0$.

Thus, $\Pi^i(\theta_s+\theta_h) \Leftrightarrow \Pi^s(\theta_s) > 0 \Leftrightarrow \Pi^h(\theta_h) > D > 0$ and similarly, $\Pi^i(\theta_s+\theta_h) \Leftrightarrow \Pi^h(\theta_h) > 0 \Leftrightarrow \Pi^s(\theta_s) > D > 0$.

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