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Outsourcing, Complementary Innovations and Growth*

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Abstract

This paper studies the parallel creation of complementary upstream and downstream innovations by independent labs to shed light on the impact of outsourcing on R&D when supply contracts are incomplete. In particular, we argue that outsourced upstream production contributes to the emergence of innovation networks by creating a demand for upstream R&D. We then analyze under which conditions this leads to faster innovation than in the case of vertically integrated production relying on integrated R&D. In the presence of incomplete supply contracts, the ex-post bargaining power of upstream and downstream parties feeds back to innovation. This determines whether outsourcing decisions leading to static gains from specialized production generate or not also dynamic gains in terms of faster innovation.

Keywords: outsourcing, complementary innovations, incomplete contracts, organization of firms.

J.E.L. Classification: L14, L23, O32, D91.

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1 Introduction

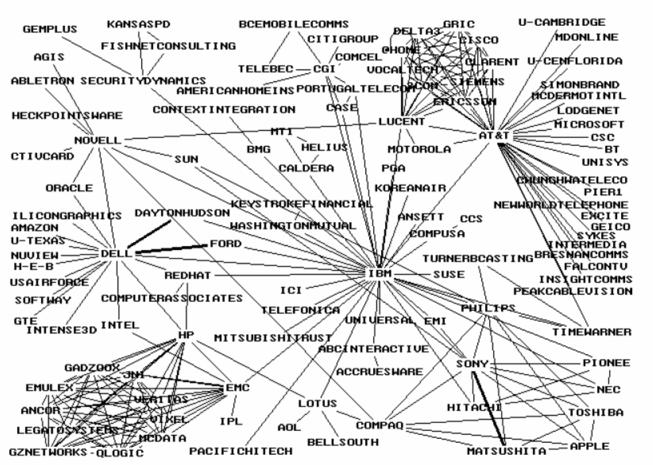
The fragmentation of the production process through outsourcing has experienced a remarkable growth in the last three decades (Feenstra, 1998). It is the most recent form of division of labor used as a business strategy to exploit gains from specialization. At the same time, outsourcing is no longer a concept limited to manufacturing and services. Given the complexities of today's technologies and supplier chains, farming out R&D is gaining remarkable importance for sustainable competitive advantage and survival in the global market. The key to success tends to increasingly hinge on the utilization of creativity and skills of specialized workers and engineers around the world linked in 'global innovation networks'. An example on two giants of the computer industry, Apple and IBM, helps clarify the concept. While IBM has adopted an 'unbundling' business strategy that goes as far back as 1969, Apple has insisted on maintaining the production of its own hardware and software in house.[1] The IBM family today consists of some of the fastest growing names in the PC computer industry such as Dell and Hewlett-Packard Co. as well as leading software and hardware producers such as Microsoft and Intel. Outsourcing has created a market for complementary innovations giving rise to a complex network of innovators that has helped IBM enjoy a much more significant role in the computer industry than Apple.[2] This has been possible through a simple division of labor, which in turn has instigated a division of knowledge creation. Figure 1 shows the depth of IBM's innovation networks in the computer industry compared to that of Apple (Tomlinson, 1999).

Could the success of a network such as IBM's be taken for granted in all sectors and under all circumstances? We address this complex question from a specific angle by focusing on a special reason why innovation networks arise, namely to serve the needs of fragmented production. From this angle causation goes from the decision to outsource production to the emergence of innovation networks, which allows us to study the conditions under which the static gains driving the outsourcing choice may be associated with dynamic losses due to slower innovation and growth. In so doing, we develop a dynamic model in which fragmented production ('outsourcing') and complementary innovations

[1] WALL STREET JOURNAL (1969).

[2] See Engardio and Einhorn (2005).

Figure 1: Innovation Networks in the Computer Industry



Source: Tomlinson (1999)

Figure 1:

('innovation networks') may arise simultaneously due to gains from specialization.

As in Grossman and Helpman (1991), in our model firms enter the market by buying the blueprints of horizontally differentiated products developed by independent labs. These are perfectly competitive and finance their R&D activities in a perfect capital market. While blueprints are protected by infinitely lived patents, technological knowledge is not fully appropriable giving rise to learning externalities that reduce the cost of R&D as experience in production cumulates through time. Differently from Grossman and Helpman (1991) but in the wake of the static model of Grossman and Helpman (2002), in our model production processes come in two types: vertically integrated and fragmented. These processes are split in two stages: upstream intermediate production and downstream final assembly. Integrated production as well as each stage of fragmented production require their own blueprints. Hence, firms enter the market as vertically integrated firms, intermediate suppliers and final assemblers by buying the corresponding blueprints. There are no economies of scope in innovation, so upstream and downstream blueprints are created independently.

There are, however, gains from specialization in that, controlling for learning effects, the creation of blueprints for vertically integrated production is more costly than the creation of an upstream and a downstream blueprints reflecting the higher complexity of the corresponding innovation process. Benefits from specialization are also present in terms of production as fragmentation is more efficient than integration.

While integrated processes are more costly to design and less efficient, they are, nonetheless, ready to run without additional burdens for the firms acquiring their blueprints. Fragmented processes face, instead, searching and matching frictions between intermediate suppliers and final assemblers. They also face contractual frictions as they require relation specific investments in order to make matched upstream and downstream blueprints perfectly compatible with each other. As in Grossman and Helpman (2002), we make the realistic assumption that contracts are incomplete due to the lack of ex-post verifiability of the quality of deliverables by third parties, which implies that relation specific investments give rise to hold-up problems. Thus, our model incorporates what Grossman and Helpman (2005, p.136) "consider to be the three essential features of a modern outsourcing strategy. First, firms must search for partners with the expertise that allows them to perform the particular activities that are required. Second, they must convince the potential suppliers to customize products for their own specific needs. Finally, they must induce the necessary relationship-specific investments in an environment with incomplete contracting".

There are a few existing contributions that are strictly related to this paper. The way we model the choice on whether to fragment production or not follows recent research that investigates outsourcing in an industry equilibrium when contracts are incomplete. The main contributions of this literature are surveyed by Helpman (2006).[3] In particular, the decision on whether production should be kept in-house or outsourced has been explored by McLaren (2000) as well as Grossman and Helpman (2002) for a closed economy, and by Antras (2003), Grossman and Helpman (2003) as well as Feenstra and Hanson (2004) for an open economy. Our focus on the dynamic effects of outsourcing is reminiscent of Glass and Saggi (2001) who develop a North-South quality ladder

[3] See Markusen (2002) as well as Barba Navaretti and Venables (2004) for a broader view of the theory of multinationals.

model of innovation in which production follows a value chain consisting of an upstream basic stage and a downstream advanced stage. They show that, by lowering production costs, outsourcing the basic stage from high-cost North to low-cost South boosts profits and therefore innovation. They do not deal, however, with matching and contractual frictions, which in our framework generate an ambiguous relation between outsourcing and innovation. Similarly, complementary innovation and matching frictions appear neither in the North-South quality ladder model with incomplete contracts by Ottaviano (2008) nor in the offshoring model with expanding product variety by Naghavi and Ottaviano (2008b). They do appear in Naghavi and Ottaviano (2008a) who nonetheless disregard the impact of outsourcing on innovation and growth in the long run, which is the main focus of the present paper. Finally, Lai, Riezman and Wang (2005) endogenize the decision to outsource R&D rather than perform it in-house by emphasizing the trade-off between the costs of information leakage and the benefits of specialization. In Acemoglu, Aghion and Zilibotti (2005) R&D is always performed in-house and firms closer to the technology frontier have a stronger incentive to outsource production in order to concentrate on more valuable R&D. By highlighting the effects of fragmented production on innovation when R&D is always outsourced, our model complements both contributions.

The core result of the present paper is that, albeit demonstrating a channel through which the outsourcing of production may breed innovation, our model reveals a tension between the static and dynamic implications of outsourcing that prevents this from always being the case. The reason is that the production decision is made weighting the higher searching and contracting costs of outsourcing against the missed specialization gains of vertical integration. In so doing, it does not take into full account its effects on the incentives to innovate. As a result, the static gains from specialized production may sometimes be associated with a slow down of innovation and growth. In particular, firms and labs favor outsourcing when there are substantial gains from specialization and the ex-post bargaining weights of intermediate suppliers and final producers reflect the relative incentives of labs to create the corresponding blueprints. When this is the case, search and hold-up frictions are minimized. Thus, when the R&D costs of intermediate blueprints are large (resp. small) with respect to the R&D cost of final blueprints, outsourcing is likely accelerate innovation if the bargaining weight of intermediate suppliers is also large (resp.small) with respect to the bargaining weight of final assemblers. These results are amplified in sectors with pronounced product differentiation.

The rest of the paper is organized as follows. Section 2 presents the basics of our model. Section 3 investigates the industry equilibrium. Section 4 discusses the consequences of firms' organizational choices on the speed of innovation. Section 5 concludes.

2 The Model

2.1 Consumption and Saving

There are L infinitely-lived households with identical preferences defined over the consumption of a horizontally differentiated good C. The utility function is assumed to be CES with unit elasticity of intertemporal substitution:

$$U = \int_0^{\infty} e^{-\rho t} \ln C(t) dt, \tag{1}$$

where $\rho > 0$ is the rate of time preference and

$$C(t) = \left[\int_0^{n(t)} c(i,t)^{\alpha} di \right]^{1/\alpha}$$

is a quantity index in which $c(i,t)$ is the consumption of variety i, $n(t)$ is the number of varieties produced, and α is an inverse measure of the degree of product differentiation between varieties. Households have perfect foresight and they can borrow and lend freely in a perfect capital market at instantaneous interest rate $R(t)$.

Using multi-stage budgeting to solve their utility maximization problem, households first allocate their income flow between savings and expenditures. This yields a time path of total expenditures $E(t)$ that obeys the Euler equation of a standard Ramsey problem:

$$\frac{\dot{E}(t)}{E(t)} = R(t) - \rho, \tag{2}$$

where we have used the fact that the intertemporal elasticity of substitution equals unity. By definition, $E(t) = P(t)C(t)$ where $P(t)$ is the exact price index associated with the quantity index

$C(t)$:

$$P(t) \equiv \left[\int_0^{n(t)} p(i,t)^{\alpha/(1-\alpha)} di \right]^{(1-\alpha)/\alpha}. \tag{3}$$

Households then allocate their expenditures across all varieties, which yields the instantaneous demand function

$$c(i,t) = A(t) p(i,t)^{-1/(1-\alpha)} \quad i \in [0, n(t)] \tag{4}$$

for each variety. In (4) $p(i,t)$ is the price of variety i and

$$A(t) = \frac{E(t)}{P(t)^{-\alpha/(1-\alpha)}} \tag{5}$$

is aggregate demand. Throughout the rest of the paper, we leave the time dependence of variables implicit when this does not generate confusion.

2.2 Innovation and Production

There are two factors of production in the economy. Labor is inelastically supplied by households. Each household supplies one unit of labor; we can hence use a single index L to refer to the number of households as well as the total endowment of labor. Labor is chosen as numeraire. The other factor is knowledge capital in the form of blueprints, the creation of which leads to the production of differentiated varieties. As in Grossman and Helpman (1991), while the length of patents on the blueprints is infinite, they depreciate at a constant rate δ.

There are two sectors, production and innovation (R&D). Perfectly competitive labs invent different types of blueprints depending on the corresponding production processes. Vertically integrated processes need a single blueprint. Fragmented processes require two blueprints ('innovation network'): one for the intermediate component and one for the final product. Firms enter by buying patents from the R&D labs. A firm can thus choose the type of patent and enter as a vertically integrated firm, an intermediate supplier or a final assembler. The number of each of these types of blueprints available at time t will be referred to as v, m, and s respectively. The marginal cost of production for vertically integrated firms is $\lambda \geq 1$ units of labor, whereas specialized intermediate producers only require 1 unit of labor per unit of input. Specialized final assemblers in turn need one unit of the intermediate component produced by their partner for each unit of the final good. Accordingly, outsourcing leads to productivity gains that stem from specialization in production.

Labs invent new blueprints at a marginal cost that depends on their types. R&D faces a learning curve, a larger number of a certain type of blueprints successfully introduced in the past makes researchers more productive in inventing that type of blueprint. For specialized blueprints, what matters is not only the number of invented patents, but also the number f of those that have actually been matched and used in production. In particular, as in Grossman and Helpman (1991), we consider a linear learning curve such that the marginal costs of innovation are k_v/v, k_m/f, and k_s/f (with k_v, k_m and k_s all positive) depending on the type of the blueprints.[4] Given this functional form, some initial stocks of implemented blueprints is needed to have finite costs of innovation at all times. We call them $v_0 > 0$ and $f_0 > 0$ for vertically integrated and specialized blueprints respectively. We finally assume that $k_s + k_m \leq k_v$ to capture the idea that the R&D cost of more complex vertically integrated blueprints is higher.

2.3 Matching and Bargaining

Outsourcing also faces additional costs that result from search frictions and incomplete contracts. After buying a patent, specialized entrants of each type must bear a search cost of finding a suitable partner in a matching process that may not always end in success. Matched intermediate suppliers also suffer hold-up problems as they each produce a relation-specific input. This input has no value outside the relation and its quality is too costly to observe by courts. Thus, the final assembler can refuse payment after the input has been produced. This gives rise to a hold-up problem in so far as, the variety-specific input having no alternative use at the bargaining stage, its production cost is sunk. The transaction costs involved in ex-post bargaining may then cause both parties to

[4] The assumed shape of the learning curve serves analytical solvability and the comparison with Grossman and Helpman (1991). In equilibrium it yields a 'size effect', meaning that larger countries grow faster. As this prediction runs against the empirical evidence, the size effect could be removed by assuming that the intensity of the learning spillover is lower, i.e. k_v/v^{ξ}, k_m/f^{ξ}, and k_s/f^{ξ} with $0 < \xi < 1$ (Jones, 1995).

underinvest in their contractual relation, reducing their joint profits.[5]

Let expressions $\dot{s} = ds/dt$ and $\dot{m} = dm/dt$ represent the flows of new final assembler and intermediate supplier entrants respectively. The number of new upstream-downstream matches at time t is determined by the following constant returns to scale matching function: $f\left(\dot{s}, \dot{m}\right) = \min(\dot{s}, \dot{m})$. If we define $r \equiv \dot{m}/\dot{s}$, the matching probability of a final assembler entrant and an intermediate supplier entrant can then be rewritten as $\eta\left(r\right) \equiv f\left(\dot{s}, \dot{m}\right)/\dot{s}$ and $\eta\left(r\right)/r$ respectively. The blueprints that correspond to unmatched entrants are instantaneously destroyed.[6]

After a successful match, intermediate suppliers produce their relation-specific inputs. Then each matched pair bargains on the division of its joint surplus, given by the prospective revenues from the sales of the corresponding variety. Since neither party has an outside option, they will eventually agree on a share that makes both better off than if they had not met. We denote the bargaining weight of the intermediate input producer by ω.

2.4 Timing

In each period t the following sequence of actions take place. Independent labs engage in R&D to innovate new patents corresponding to vertically integrated firms, upstream specialized intermediate producers and downstream specialized assemblers. In the production sector firms choose their mode of entry by purchasing the respective blueprints. Firms who have purchased specialized blueprints search for partners to form an upstream-downstream chain. Their effort could end in a successful or an unsuccessful match. Each matched intermediate producer manufactures the input needed by its partner, while unmatched entrants exit and their patents are destroyed. Once input production is completed, the outsourcing pair bargain over the share of total revenues from final sales that goes to each partner and inputs are handed over to assemblers. Final assembly then takes place and the

[5] This approach is similar to the transaction-cost approach adopted by Grossman and Helpman (2002, 2003). Marin and Verdier (2003) as well as Antras (2003) take on a different approach in line with the property rights theory of Grossman and Hart (1986) and Hart and Moore (1990), which states that agreements among stakeholders within a vertically integrated firm are also incomplete.

[6] This assumption is made for analytical convenience. The survival of unmatched blueprints would increase the number of statuses through which blueprints can transit without adding much insight.

final products are sold to households together with those supplied by vertically integrated firms.

3 Industrial Organization

3.1 Production

At time t the instantaneous equilibrium is found by solving the model backwards from final production to R&D given the number of blueprints invented for each organizational mode. Varieties can be sold to final customers by two types of firms: vertically integrated firms and final assemblers. A typical vertically integrated firm faces a demand curve derived from (4) and a marginal cost equal to λ. It chooses its scale by maximizing its operating profit

$$\pi_v = p_v y_v - \lambda x_v, \tag{6}$$

where x_v is the amount of the intermediate input produced and $y_v = x_v$ is the final output. Optimal output and price are then given by:

$$x_v = y_v = A\left(\frac{\alpha}{\lambda}\right)^{\frac{1}{1-\alpha}} \tag{7}$$

and

$$p_v = \frac{\lambda}{\alpha}. \tag{8}$$

Replacing these values in (6) results in operating profit equal to

$$\pi_v = (1-\alpha)\, A\left(\frac{\alpha}{\lambda}\right)^{\frac{\alpha}{1-\alpha}}, \tag{9}$$

which is an increasing function of product differentiation $(1-\alpha)$ and a decreasing function of the marginal cost (λ).

Turning to the outsourcing mode, there is a one-to-one equilibrium relationship between the number of matched assemblers, the number of matched intermediate suppliers, and the number of outsourced varieties; they are all equal to f. The joint surplus of a matched pair of entrants is given by the revenues from the final sales of the corresponding variety $p_s y_s$. This is divided according to the bargaining weights of the two parties. Accordingly, a share $(1-\omega)$ goes to the final assembler giving operating profits of

$$\pi_s = (1 - \omega) p_s y_s, \tag{10}$$

and the remaining share ω goes to the intermediate supplier. The latter must decide in the previous stage how much input x_m to produce anticipating this share, which incurs a cost of x_m units of labor. Therefore, it maximizes

$$\pi_m = \omega p_s y_s - x_m, \tag{11}$$

which implies an intermediate and final output equal to

$$x_m = y_s = A\left(\alpha\omega\right)^{\frac{1}{1-\alpha}} \tag{12}$$

with associated final price

$$p_s = \frac{1}{\alpha\omega}. \tag{13}$$

Using these results in (10) and (11), and recalling that specialized intermediate and final entrants face probabilities $\eta\left(r\right)$ and $\eta\left(r\right)/r$ of being matched, their expected profits are respectively:

$$\pi_s^e = \eta(r)\left(1 - \omega\right) A\left(\alpha\omega\right)^{\frac{\alpha}{1-\alpha}} \tag{14}$$

and

$$\pi_m^e = \left(1 - \alpha\right) \frac{\eta(r)}{r} \omega A\left(\alpha\omega\right)^{\frac{\alpha}{1-\alpha}}. \tag{15}$$

Substituting (8) and (13) into (3) and (5) allows us to write aggregate demand as

$$A = \frac{E}{v\left(\frac{\alpha}{\lambda}\right)^{\frac{\alpha}{1-\alpha}} + f\left(\alpha\omega\right)^{\frac{\alpha}{1-\alpha}}}, \tag{16}$$

where v is the number of vertically integrated firms and f is the number of matched pairs of specialized producers that are active at time t.

3.2 Innovation

In the entry stage, the output from the R&D labs determines the laws of motion of v and f. For vertically integrated firms, we have

$$\dot{v} = \frac{v L_v^I}{k_v} - \delta v \tag{17}$$

where $\dot{v} \equiv dv/dt$, L_v^I is labor employed in inventing new blueprints for vertically integrated production, v/k_v is its productivity, and δ is the rate of depreciation. For specialized pairs we have

$$\dot{f} = \eta(r)\dot{s} - \delta f \quad \text{with} \quad r \equiv \frac{\dot{m}}{\dot{s}}, \ \dot{s} = \frac{fL_s^I}{k_s}, \ \dot{m} = \frac{fL_m^I}{k_m} \tag{18}$$

where $\dot{f} \equiv df/dt$, L_s^I and L_m^I are labor employed in inventing new final assembler and intermediate supplier blueprints, and f/k_s and f/k_m are their respective productivities.

Learning implies that the values of blueprints are not constant. As innovation cumulates, it becomes increasingly cheaper to create new patents. Being priced at marginal cost, their values fall through time. Specifically, if we call J_j the asset value of a patent, patents are priced at marginal cost due to perfect competition in R&D requiring $J_v = k_v/v$, $J_m = k_m/f$ and $J_s = k_s/f$. This implies

$$\frac{\dot{J}_v}{J_v} = -\frac{\dot{v}}{v}, \ \frac{\dot{J}_m}{J_m} = \frac{\dot{J}_s}{J_s} = -\frac{\dot{f}}{f} \tag{19}$$

Labs pay their researchers by borrowing at the interest rate R while knowing that the resulting patents will generate instantaneous dividends equal to the subsequent expected profits of the corresponding firms. Arbitrage in the capital market then implies

$$R = \frac{\pi_v}{J_v} - \frac{\dot{v}}{v} - \delta \tag{20}$$

and

$$R = \frac{\pi_j^e}{J_j} - \frac{\dot{f}}{f} - \delta, \ j = m, s \tag{21}$$

where $\dot{v}/v$ and $\dot{f}/f$ represent the rate at which new blueprints are innovated in the case of vertical integration and outsourcing respectively. These results give

$$R + \delta = \frac{v\pi_v}{k_v} - \frac{\dot{v}}{v} = \frac{f\pi_s^e}{k_s} - \frac{\dot{f}}{f} = \frac{f\pi_m^e}{k_m} - \frac{\dot{f}}{f}, \tag{22}$$

which pins down the interest rate in the Euler equation (2).

Finally, the aggregate resource constraint (or full employment condition) closes the characterization of the instantaneous equilibrium. Since labor is used in innovation and in intermediate production by both vertically integrated and specialized producers, we have $L = L_v^I + L_s^I + L_m^I + v\lambda x_v + f x_m$.

By (7), (12), (17) and (18), the condition can be rewritten as

$$L = k_v \left(\frac{\dot{v}}{v} + \delta \right) + k_s \frac{\dot{s}}{f} + k_m \frac{\dot{m}}{f} + v\lambda A \left(\frac{\alpha}{\lambda} \right)^{\frac{1}{1-\alpha}} + fA\,(\alpha\omega)^{\frac{1}{1-\alpha}} . \tag{23}$$

3.3 Organization

In any instant t there is never simultaneous invention of both vertically integrated and specialized blueprints. This would be the case if all equalities in (22) held at the same time. This is generally impossible. To see this, proceed in two steps. First consider that new outsourcing agreements are signed only if there is new creation of both intermediate supplier and final assembler blueprints, which requires

$$\frac{f\pi_m^e}{k_m} = \frac{f\pi_s^e}{k_s}.$$

Using (14) and (15), this yields a fixed ratio of intermediate suppliers over final assemblers

$$r = \overline{r} \equiv \frac{k_s}{k_m} \frac{(1-\alpha)\,\omega}{1-\omega}. \tag{24}$$

This implies that the two types of specialized blueprints have to be invented in fixed proportions.

Turning to the second step, a case with only vertically integrated firms reflects Grossman and Helpman (1991), as the model has no transitory dynamics and jumps instantaneously to its balanced growth path.[7] Simple inspection reveals that, by analogy, the same property applies when only specialized firms or all types of firms are simultaneously active. Along the balanced growth path all variables either grow at the same rate or do not grow at all. Therefore, for both vertical and specialized blueprints to be generated at the same time, $\dot{f}/f = \dot{v}/v = g$ must hold. Under this constraint, $v = v_0 e^{gt}$ and $f = f_0 e^{gt}$ always hold. Then, substituting $J_v = k_v/v$ and $J_j = k_j/f$ for $j = m, s$ into (20) and (21) gives

$$\frac{\pi_v v_0 e^{gt}}{k_v} = \frac{\pi_j^e f_0 e^{gt}}{k_j}, \ j = m, s$$

which implies

$$\frac{(1-\alpha)\,\lambda^{-\frac{\alpha}{1-\alpha}} v_0}{k_v} = \frac{\eta(\overline{r})\,(1-\omega)\,\omega^{\frac{\alpha}{1-\alpha}} f_0}{k_s} \tag{25}$$

[7] See Grossman and Helpman (1991) pp. 54-56.

where $\overline{r}$ is the bundling parameter defined in (24). Both its sides being constant, (25) is satisfied only for a zero-measure set of parameter values. Therefore, in general, specialized and vertically integrated blueprints are not invented together in equilibrium. In particular, only the former are created when

$$\lambda > \tilde{\lambda} \equiv \frac{1}{\omega} \left[\frac{k_s}{k_v} \frac{v_0}{f_0} \frac{(1-\alpha)}{(1-\omega)} \frac{1}{\eta(\overline{r})} \right]^{\frac{1-\alpha}{\alpha}} \tag{26}$$

and only the latter when the reverse is true. Hence, we have:

Proposition 1 *Firms choose outsourcing rather than vertical integration if and only if* $\lambda > \tilde{\lambda}$.

Higher initial experience in vertically integrated (v_0) or in specialized processes (f_0) makes new blueprints of the same type less costly to invent. Outsourcing is hence selected when there is relatively higher initial experience in outsourcing (small $v_0/\ f_0$); when specialized final assemblers have a high chance of finding specialized intermediate suppliers (high $\eta(\overline{r})$); when product differentiation is weak so that the profit share of revenues of vertically integrated firms is small (small $1-\alpha$) relative to the share appropriated by final assemblers through bargaining (large $1-\omega$); when vertical revenues are relatively low due to large gains from specialization (large λ) and little intermediate underproduction is caused due to sufficient supplier bargaining power (large ω); and when the blueprints for specialized assembly are relatively cheap compared with those for vertically integrated production (small k_s/k_v).

The matching probability of specialized assemblers itself depends on the relative R&D costs (k_s/k_m), the relative profit margin of final assemblers and intermediate suppliers ($(1-\alpha)/(1-\omega)$), and the supplier bargaining power (ω). When assemblers' R&D costs are relatively large, profit margin relatively small, and supplier bargaining power strong, the minority of entrants are final assemblers, so they are surely matched ($\eta(\overline{r}) = 1$). In this case, their matching probability is unaffected by marginal parameter changes. Here, stronger supplier bargaining power has two opposite effects: it promotes intermediate production but at the same time discourages final production. While the first effect fosters outsourcing, the second hampers it. Higher product differentiation (small α) reinforces the second effect because it makes demand more elastic, hence more sensitive to small price differences. High intermediate prices due to a large ω thus map into small final quantities sold. The best scenario for outsourcing strikes the optimal balance between those two effects, which occurs at $\omega = \alpha$. When assemblers' R&D costs are relatively small, their profit margin relatively large, and supplier bargaining power weak, the majority of entrants are final assemblers reducing their chances of being matched $(\eta(\overline{r}) < 1)$. In this situation, the impact of ω on the propensity to outsource becomes unambiguously positive. The reason is that, by fostering intermediate entry and hampering final entry, stronger supplier bargaining power (larger ω) raises the matching probability of final assemblers.

4 The Speed of Innovation

4.1 Vertical Integration

When condition (26) does not hold, no labor is allocated to specialized innovation ($L_s^I = L_m^I = 0$), so no new specialized patent is ever created: $\dot{s} = \dot{m} = 0$ and asymptotically $f = 0$. Along a balance growth path, we have $\dot{v}/v = g_v$ and $\dot{E} = 0$.[8] This allows us to write the full employment condition (23) and the Euler condition (2) as:

$$L = k_v (g_v + \delta) + \alpha E$$

and

$$0 = \frac{(1-\alpha) E}{k_v} - g_v - \rho - \delta.$$

These can be solved to yield the equilibrium values of expenditures and the speed of innovation:

$$E_v^G = L + \rho k_v,\; g_v^G = (1-\alpha)\frac{L}{k_v} - \alpha\rho - \delta. \tag{27}$$

Under vertical integration innovation is boosted by weak time preference (small ρ), slow depreciation (small δ), large size of the economy (large L), small R&D cost (small k_v), and pronounced product differentiation (small α). While a large size of the economy also gives large expenditures, weak time preference and small R&D costs depress them. A high rate of depreciation hence lowers both the speed of innovation and expenditure by reducing the incentive to innovate and diverting labor

[8] The initial stock of specialized blueprints depreciates through time and asymptotically disappears since it is not refilled. See Naghavi and Ottaviano (2008a) for details.

from alternative uses. Differently, stronger time preference (larger ρ) has a negative impact on the rate of innovation but a positive one on expenditures since it biases intertemporal decisions towards consumption and away from saving. Finally, higher costs of innovation (larger k_v) increases expenditures and slows innovation whereas a larger economy (larger L) supports proportionately larger expenditures accompanied by a faster rate of innovation.

4.2 Outsourcing

When condition (26) holds, no labor is allocated to vertical innovation ($L_v^I = 0$), so no vertically integrated blueprints are ever created: $\dot{v} = 0$ and asymptotically $v = 0$.[9] Along a balanced growth path, we have $\dot{f}/f = g_f$ and $\dot{E} = 0$. This allows us to write the long run full employment condition (23) and the Euler condition (2) as:

$$L = \frac{k_s + k_m \overline{r}}{\eta(\overline{r})}(g_f + \delta) + \alpha\omega E$$

and

$$0 = \frac{\eta(\overline{r})(1-\omega)E}{k_s} - g_f - \rho - \delta.$$

Given the definition of $\overline{r}$ in (24), these can be solved together to yield

$$E_f^G = L + \rho \frac{k_s}{\eta(\overline{r})} \frac{1-\omega\alpha}{1-\omega}, g_f^G = \eta(\overline{r})(1-\omega)\frac{L}{k_s} - \rho\omega\alpha - \delta, \tag{28}$$

which depend on the matching probability of assembler entrants $\eta(\overline{r})$. Hence, there are two cases. If there are fewer assemblers than intermediate entrants ($\overline{r} > 1$), then the former are surely matched, so $\eta(\overline{r}) = 1$. Accordingly, (28) becomes:

$$E_s^G = L + \rho k_s \frac{1-\omega\alpha}{1-\omega}, \; g_s^G = (1-\omega)\frac{L}{k_s} - \rho\omega\alpha - \delta. \tag{29}$$

If there are more assembler than intermediate entrants ($\overline{r} < 1$), then the latter are surely matched, so $\eta(\overline{r})/\overline{r} = 1$. This allows us to write (28) as:

$$E_m^G = L + \rho k_m \frac{1-\omega\alpha}{(1-\alpha)\omega}, \; g_m^G = (1-\alpha)\omega\frac{L}{k_m} - \rho\omega\alpha - \delta. \tag{30}$$

[9] The initial stock of vertically integrated blueprints depreciates through time and asymptotically disappears since it is not refilled. See Naghavi and Ottaviano (2008a) for details.

As under vertical integration, in both cases innovation is fostered by weak time preference (small ρ), slow depreciation (small δ), large size of the economy (large L), small R&D cost (small k_s or k_m), and pronounced product differentiation (small α). A large size of the economy also supports large expenditures whereas weak time preference as well as small R&D costs depress them. The impact of product differentiation on expenditure is different under the two matching cases. The reason is that the annuity value of the initial stock of blueprints depends positively on the dividends to assembler patents and negatively on the matching probability of new assembler entrants. When matching is certain ($\overline{r} > 1$), little differentiation (large α) depresses dividends and thus expenditures. When matching is uncertain ($\overline{r} < 1$), little differentiation depresses the matching probability more than the dividends, which sustains expenditures. Finally, when assemblers are uncertain about finding a partner, higher supplier bargaining power (larger ω) increases assemblers' matching probability by encouraging supplier entry. This reduces expenditures and promotes innovation ($dg_m/d\omega > 0$ provided that $g_m > 0$). On the other hand, when assemblers are surely matched ($\overline{r} > 1$) a larger ω is associated with larger expenditures and slower rate of innovation. This is because the matching probability no longer plays a role, while the return to assembly falls, thus discouraging the creation of new assembler blueprints.

4.3 Bargaining Power

We now analyze the role of the bargaining weight ω on our results. Particularly, we highlight a direct link between innovation and the proportion of suppliers over assemblers that enter the market, $\overline{r}$, which is in turn determined by the bargaining weight granted to each side. The top panel of Figure 2 displays the matching probability of final assemblers a a function of ω. It shows that a higher ω encourages supplier entry thereby raising assembler matching probability until there is an equal number of the two types of entrants. A higher number of suppliers thereafter only reduces their own matching probability, while leaving the assemblers' unchanged.

The middle panel of Figure 2 shows the impact of ω on the speed of innovation. The flat line represents the innovation rate under vertical integration, which shows that outsourcing yields a

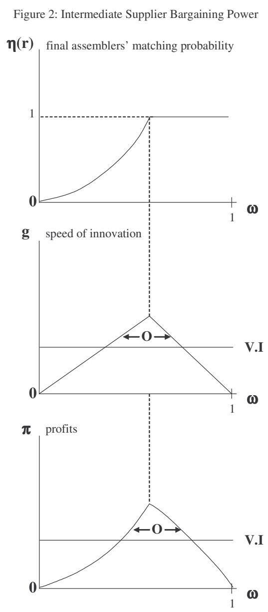


Figure 2:

faster pace of innovation than vertical integration when the bargaining weight of suppliers takes intermediate values. In particular, the supplier weight that yields the maximum speed of innovation is the critical ω that just sets $\overline{r}$ in (24) equal to one:

$$\omega^* = \frac{k_m}{k_s(1-\alpha)+k_m}. \tag{31}$$

For $\omega = \omega^*$, the same number of suppliers and assemblers enter the market ($\dot{m} = \dot{s}$), so search costs are minimized as both groups are certain of being matched. In other words, in the search process the negative intra-group externalities exactly offset the positive inter-group externalities. For higher $\omega > \omega^*$, we have $\overline{r} > 1$ and thus $\eta(\overline{r}) = 1$. Accordingly, a higher bargaining weight has no impact on the matching probability of final assemblers leaving only a negative effect on their returns, their incentives to enter, and hence innovation. The critical value ω^* is increasing in α and decreasing in k_s/k_m: a larger bargaining weight of suppliers is needed to compensate the stronger incentive to enter final assemblers have when product differentiation rises and their relative entry costs fall.

The bottom panel in Figure 2 compares the profitability of vertical integration with that of outsourcing showing that the latter is preferred by firms in the region of ω such that the number of supplier and assembler entrants are similar. This suggests that outsourcing tends to take place in situations where it accelerates innovation. Nonetheless, the overlap is not complete. Recall from inequality (26) that all firms choose to outsource if λ is sufficiently high. On the other hand, (27), (29) and (30) reveal that whether outsourcing promotes faster innovation than vertical integration is independent from λ. The reason is that, once all firms have chosen to vertically integrate or outsource, λ no longer enters their profits, as they all enjoy the same market share (E/v or E/f respectively). This creates circumstances under which all firms outsource when vertical integration would lead to a higher speed of innovation. Specifically, using (27), (29) and (30) to set $g_v^G = g_s^G$ and $g_v^G = g_m^G$, we can determine the range of ω in which outsourcing speeds innovation. The upper and lower bounds of this range are

$$\breve{\omega}_s = 1 - \frac{k_s}{k_v}\frac{L(1-\alpha)}{L+\alpha\rho k_s} \text{ and } \hat{\omega}_m = \frac{k_m}{k_v}\frac{L(1-\alpha)-\alpha\rho k_v}{L(1-\alpha)-\alpha\rho k_m}.$$

They correspond to the two scenarios of $\eta(\overline{r}) = 1$ and $\eta(\overline{r}) < 1$ respectively and can be ranked $\breve{\omega}_s > \hat{\omega}_m$ as long as $k_v > L[k_s(1-\alpha)+k_m]/\left(L+\alpha\rho k_s\right)$. The range $[\hat{\omega}_m, \breve{\omega}_s]$ in which outsourcing brings faster innovation is wider the higher the relative R&D cost advantage for specialized blueprints with respect to vertically integrated ones (the smaller k_s/k_v and k_m/k_v). We can then write:

Proposition 2 *Firms choose outsourcing rather than vertical integration and their decision leads to accelerated innovation if and only if* $\lambda > \tilde{\lambda}$ *and* $\hat{\omega}_m < \omega < \breve{\omega}_s$.

If $\lambda > \tilde{\lambda}$ and $\omega < \hat{\omega}_m$ or $\omega > \breve{\omega}_s$, firms choose outsourcing when vertical integration maximizes the speed of innovation. If $\lambda < \tilde{\lambda}$ and $\hat{\omega}_m < \omega < \breve{\omega}_s$, firms choose vertical integration when outsourcing maximizes the speed of innovation. If $\lambda < \tilde{\lambda}$ and $\omega < \hat{\omega}_m$ or $\omega > \breve{\omega}_s$, firms choose vertical integration and this promotes innovation.

The patterned region in Figure 3 represents the combinations of λ and ω where outsourcing is chosen by firms for given parameter values. The figure then illustrates whether the organizational decisions of firms coincide with a higher speed of innovation in the economy. The shaded pattern area shows the region where firms outsource and their decision to do so accelerates the rate of innovation. On the other hand, the white patterned area shows the area where firms' decision to

Figure 3: Dynamic Effects of Outsourcing on Innovation

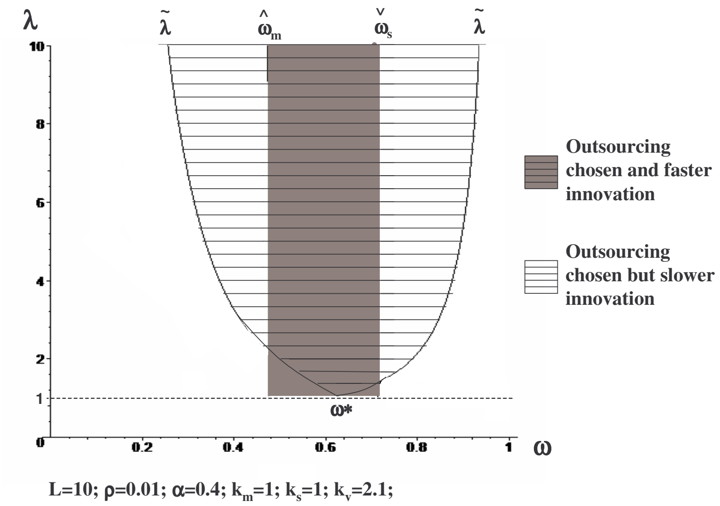


Figure 3:

outsource generates slower innovation than vertical integration.

We can conclude that outsourcing is chosen by firms and encourages innovation when there are substantial gains from specialization (large λ) and the ex post bargaining weights of intermediate suppliers and final producers tend to reflect the relative incentives of labs to create the corresponding blueprints (ω close to ω^*). When this is the case, search and hold-up frictions are minimized. Thus, by (31), *in sectors in which the R&D costs of intermediate blueprints are large (resp. small) with respect to the R&D cost of final blueprints, outsourcing is likely to accelerate innovation when the bargaining weight of intermediate suppliers is also large (resp. small) with respect to the bargaining weight of final assemblers.* These results are amplified in sectors with pronounced product differentiation.

5 Conclusion

We have proposed a model of horizontal product innovation with outsourcing to explore the implications of fragmented production for innovation. The model focuses on situations in which the fragmentation of production leads to complementary innovations by upstream and downstream labs ('innovation networks'). The model has allowed us to characterize the conditions under which the organizational choices of firms in terms of production foster or hamper innovation.

The analysis has highlighted the importance of the bargaining conditions between upstream and downstream producers in the course of the formation of networks for the latter to promote innovation and growth. We have shown that the long run effects of fragmented production on innovation are sector specific and depend on the structure of the market. In particular, in sectors in which the R&D costs of upstream innovations are large (resp. small) with respect to the R&D cost of downstream innovations, outsourcing is likely promote growth only when the bargaining weight of intermediate suppliers is also large (resp. small) with respect to the bargaining weight of final assemblers. As the bargaining weights diverges from these scenarios, it becomes more likely for the static gains from outsourced production to lead to dynamic losses due to slower innovation. This stems from the fact that producers partially neglect the impact of their organizational choices on innovation. Hence, although the interests of firms and labs are generally aligned, the positive link between the organization of firms and the speed of innovation cannot be taken for granted.

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