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Divide to conquer?
The Silicon Valley - Boston 128 case revisited

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Abstract

The present paper investigates the role of decentralisation for the adaptability of production networks in clusters. It develops a simulation model able to test to what extent decentralised, networked clusters with many small firms (Silicon Valley) can be more adjustable than those composed of fewer, large companies (Boston 128). The model finds that for limited degrees of product complexity, decentralisation increases cluster adaptability at the expense of greater instability. This increases the risk of firm failure. Moreover, it is shown that agent numbers matter greatly for the competitiveness of decentralised clusters. Only if they host more firms than integrated cluster types is their lead in performance maintained. As a result, an additional condition had to be met to allow the Silicon Valley type to outperform the Boston 128 one: Greater firm numbers and strong startup dynamics.

Keywords: Clusters, Adjustment, *N*/*K* model, Simulation, Decentralisation

JEL - code(s). L 22, C 63, R11

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Any remaining errors and defiicencies are mine.

1 Introduction

Ever since the works of Coase (1937), firms and markets have been seen as two opposing forms for organising economic transactions. While subsequent literature has extended the range of governance mechanisms, the relative advantage of (quasi-) market or (quasi-) hierarchical organisational forms has been argued to depend on environmental conditions. Long-term transactions in uncertain environments favour integration in a hierarchical firm while heterogeneity and geographical spread of transactions, price volatility as well as the current size of a firm pose a limit on the extent of integration (Coase, 1937, pp.391-397).

More recently, the question of decentralisation versus integration has received attention due to its implications for the long-term performance of organisations. With increased technological complexity and dynamism, deregulation and globalisation of markets, competitive pressure intensified (Hamel and Prahalad 1994; D'Aveni 1994; Brown and Eisenhardt 1998). The response of many firms has been to concentrate on their core competencies and shift non-core activities outside the organisation (Harrison 1994*b*). The has led to an increase in inter-organisational transactions, implying a growing embeddedness of firms in different inter-organisational networks. While these inter-firm networks are argued to increase firm performance and flexibility (Helsley and Strange 2002; Ahuja 2000; Feldman 1999; Audretsch and Feldman 1996; Pisano 1991; Freeman 1990), they also increase interdependence with the activities of other, autonomous actors. As a result, inter-firm networks can assist firm performance but can also play a pivotal role in firm decline (Uzzi 1997*a,b*; Grabher 1993). In a world characterised by increasingly fast dynamics, the question of whether and how inter-firm networks help or hamper firm adaptability is therefore not a trivial one.

The present paper investigates this aspect by analysing the link between inter-firm network structures and adaptability in the specific context of industrial clusters. Clusters, i.e. non-random spatial concentrations of firms (Ellison and Glaeser 1997; Glaeser, Dumais and Ellison 2002), are characterised by spatially bounded inter-organizational networks (Cappellin 2003) that are particularly varied and strong because production in clusters is usually conducted by a number of independent firms rather than one integrated organisation. In fact, already in the early writings, clusters were seen as antipodes to production in large firms (Piore and Sabel 1984; Sabel 1989; Scott 1988; Storper and Harrison 1991). Their advantages lie with three aspects Marshall (1920, pp. 280-284): First, the smaller size of firms implies better control of employees, easier communication, and less waste of material. Additionally, production with independent firms specialising in different stages of the value chain allows for more flexibility in product characteristics and output quantities (Goldstein and Gronberg 1984).[1] Third and most importantly, a spatial concentration of firms and the resulting inter-organisational networks lead to the emergence of external economies of scale (agglomeration externalities), including (Marshall 1920, pp. 271): knowledge spillovers due to inter-firm observation and collaboration; pooled labour markets due to immigration and local firms' training activities; as well as scale and specialisation benefits due to a division of labour. At the same time, large firms were argued to have several scale advantages improving the availability of resources, opportunities for environmental monitoring and personnel training among other things (Florida and Kenney 1990; Harrison 1994*a,b*). As a result, the nature of industries would determine whether: "*the full economies of division of labour can be*

[1] This flexibility is achieved by changing combinations of suppliers and end-producers.

obtained by the concentation of large numbers of small businesses of a similar kind in the same locality; and how far they are attainable only by [...] production on a large scale" (Marshall 1920, p. 277).

This notion of the advantages of small firm networks in clusters over large integrated organisations was taken up in later work (Becattini 1994, 2002; Brusco 1982, 1990; Pyke, Beccattini and Sengenberger 1990). At the same time, cases of successful clusters with mainly large companies have been observed (Markusen 1996). The question of the optimality of small versus large firm clusters - i.e. the relative advantage of integrated versus disintegrated production - is further complicated by contradicting empirical evidence. While recent developments in Italian small firm clusters have pointed out that larger firms tend to become more prominent as the economic environment changes (Boschma and Lambooy 2002; Cainelli and Zoboli 2004; Lombardi 2003), a comparison of adjustment to change in the Silicon Valley and Boston 128 computing clusters (Saxenian 1994) finds that Silicon Valley with its predominance of small firms fared better in adjusting to market crises. Parallel to concerns in organisation theory, the cluster literature therefore faces the question of whether or not decentralised structures with mainly small, networked firms are more responsive to change than cases in which production in the cluster takes place in integrated, large firms.

The present paper investigates the role of decentralisation for the adjustability of production networks in clusters by using two techniques that have recently become prominent in organisation studies:[2] Agent-based modelling and the *N*/*K* framework. It finds that decentralised clusters comprised of many small firms perform better in adjusting to changes in their competitive environment if product complexity is limited. This increase in performance however comes at the price of greater instability of adjustment processes and is conditional on larger firm numbers. As a result, small firm clusters require strong startup mechanisms to compensate for organisational failures and to maintain their positive dynamics. In the Silicon Valley (Saxenian 1994), this condition for the greater performance of disintegrated cluster structures was very prominent. This could explain why the Valley out-performed its more integrated counterpart (Boston 128) while other areas with decentralised small firm clusters did not manage to do the same.

2 The model

The issue of the role of division of labour for adjustability is very prominent in Saxenian's comparison of development of the Silicon Valley - Boston 128 computer clusters (ibid 1994). This case is particularly interesting as these regions exhibit substantial similarities. Both had their origin in university research and military spending, exhibited similar technological competencies (with a head start for the Boston's Route 128), and were hailed as sources of "*technological vitality, entrepreneurship, and extraordinary economic growth*" (Saxenian 1994, p.1). Nevertheless, their performance began to diverge after a series of crises in the early 1980s. While the Boston 128 companies lost their initial lead on the Valley, the latter was relatively swift in recapturing and expanding its previous success. It was often argued that this differing performance was due to "*the limits of an independent firm-based industrial*

[2] See Siggelkow and Rivkin 2005; Rivkin and Siggelkow 2003; Rivkin 2000; Ethiraj and Levinthal 2004*a*; Dosi, Levinthal and Marengo 2003; Siggelkow and Levinthal 2003; Levinthal 1997, 2000 among many others.

system in an environment of technological and market volatility. While the Route 128 system [...] provided the stability that is critical in an environment of volume markets and price-based competition, it was inadequate for the accelerating pace of technological and market change in semiconductors" (Saxenian 1994, p.80).[3]

The present model investigates the *conditions* for such an outcome, i.e. the extent to which decentralisation helps adjustability given that a growing division of labour between firms in production networks also increases interdependence between them. It takes two ideal-typical setups as its point of departure. The 'Silicon Valley' type cluster composed of many small, networked firms versus the 'Boston 128' type where companies are fewer, larger and more integrated. The model then studies the adaptability of both types of clusters to changing environments. It views clusters as composed of a local value chain encompassing all activities in the production process. This production process is divided between a number of agents (firms). The interplay of firm activities, interdependence between them and environmental conditions then determines, how successful the cluster is at any given time. Changes in the cluster's environment in turn impact on its success, thereby prompting agents to adjust. It will be investigated, how different degrees of division of labour (decentralised, small firm versus integrated large firm cluster) impact on cluster adjustability to environmental change. The following sections revisit the three constituent components of the model (environment and change, production, as well as cluster dynamics) in more detail.

2.1 Environment

The N/K model developed by Kauffman (1993) is a generic tool to model complex systems. It characterises any system by the number of elements N and the degree of interdependence K. Each system element n can take on two possible states $a_n \in \{0,1\}$, which have a specific fitness value w_n. As is apparent from (Eq. 1), w_n is conditional on the state of the element itself as well as on the state of any interdependent elements if $K \neq 0$:

$$w_n = c(a_n; a_{n_1} \ldots a_{n_K}). \tag{1}$$

The fitness value of each element state is determined by a random draw from a uniform distribution between 0 and 1. In the case of interdependence between elements, one draw is performed for each possible combination of element states. For each possible configuration M of the system's elements, the N/K model thus determines a fitness value $W(M)$, which is equal to the mean of the fitness values of all elements:

$$W(M) = \frac{1}{N} \sum_{n=1}^{N} w_n. \tag{2}$$

Taking the 2^N different configurations of system elements and their fitness values then yields

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[3] This is not to say that the Boston 128 was entirely unsuccessful in handling the crisis in the long run (Glaeser 2003). Moreover, the diverging performance of Silicon Valley versus the Boston 128 has also been explained as a consequence of other factors rather than the relative benefits of decentralisation versus integration investigated here. See Kenney and von Burg (1999) for an explanation based in different technological trajectories exhibited by both regions. Nonetheless, the present case is often used as a case in point to emphasise the benefits of decentralisation over integration in clusters.

the system's fitness landscape. The shape of this fitness landscape regarding its smoothness and the fitness values associated with different configurations M is determined by the system's environment. Put differently, the environment decides on the fitness values of all (combinations of) element states. Changes in system fitness can then emerge from two sources. The first type of change is usually *endogenous* insofar as the system (or its agents) can bring it about. It concerns modifications in the system's configuration M. The second type of change is *exogenous*, i.e. it cannot be influenced by the system itself. This type of change refers to an alteration of element fitness values regardless of the current system configuration. This second type of change will be argued to correspond to changes in the system's environment, which will be represented as an alteration of the fitness landscape. Adjustability then refers to the system's ability of finding good (fit) configurations M through endogenous change after the exogenous change in the fitness landscape occurred. This ability will be shown to depend on the system's setup and dynamics.

2.2 Production

Let the elements of the system be the activities in the production process of the cluster, i.e. $n \in \{1,,N\}$ constitutes the cluster's value chain. Each of the element states $a_n \in \{0,1\}$ then represents different ways of conducting an activity in production (e.g. research). In clusters, the activities in the local value chain are not conducted by one integrated company as production takes place among several independent firms. As a result, the model assumes that the M value chain activities are split into a number r of production segments S_i. This decomposition of the value chain is done in such a way that each activity is allocated to one segment only, i.e. there is no overlap between segments:

$$M = S_1 \cup S_2 \cup ... S_r = \cup_{i=1}^{r} S_i \quad (3)$$

Depending on the type of cluster investigated (Silicon Valley versus Boston 128), the degree of division of labour and therefore the number and size of production segments differs. It is argued here that Silicon Valley type clusters are characterised by a number of small firms, i.e. they exhibit a greater number of smaller production segments S_i. Boston 128 type clusters in turn comprise, fewer, larger companies that control larger production segments thereby reducing the total number of segements. Within each segment, a number of firms execute and control the segment's production steps. The configuration of the system is then made up of the configurations of all segments (S_i). The fitness of each production segment can in turn be determined as the average value of the fitness contribution of its elements:

$$w(S_i) = \frac{1}{S_i} \sum_{n \in S_i} w_n \quad (4)$$

Let $a_n^u(t)$ then denote the state of a production step controlled by a firm u at time t. As was mentioned before, this state can be either 0 or 1. This element state has a fitness value $w(a_n^u)$, which can be interdependent with the states of other system elements. Assuming a given interdependence between elements in the value chain and a division of that value chain into segments implies that interdependence can occur within the same production segment or between segments. In other words, the activities controlled by a firm on one production segment can be mutually interdependent. Moreover, it is possible that the fitness of activities of a firm is influenced by the actions of firms located in other production segments. This aspect captures the notion of interdependence between agents, which is particularly strong in disintegrated production networks. It also implies that individual activities can lead to unanticipated or even unintended aggregate effects (Axelrod and Cohen 1999).

2.3 Dynamics

Based on this setup, the dynamics of cluster adjustment to changing environmental conditions can be separated into three stages occurring in each simulation step. In *t*=0, all agents in the cluster start with a randomly assigned configuration of their production segment (S_i^u). In subsequent steps, the model dynamics map out as follows. First, agents search for, test and select new configurations of the activities belonging to their production segment. Second, agents propose the new configuration for representation in their group, i.e. they bid for representation at the level of the production segment. Third, all winning agent configurations in each segment are taken together, thereby determining the actual fitness of the cluster and its agent groups. The following sections describe each aspect in more detail.

2.3.1 Agent behaviour: Search, test, selection

Let $S^u(t)$ denote the configuration of production steps within the segment of a firm *u* at time *t*. This configuration is made up of the states of all elements in the firm's production segment, i.e.

$$S^u(t) = (a_n^u(t))_{n \in S^u}. \tag{5}$$

In each simulation step, the firm tries to improve this configuration by searching, testing and selecting new configurations. The first part of this process, *search*, has the firm propose a tentative new configuration for the next simulation step $\tilde{S}^u(t+1)$.[4] The firm arrives at this proposed new configuration by changing the states of all elements in its current configuration $S^u(t)$ with a given probability *p*. This leads to a new, proposed configuration $\tilde{S}^u(t+1)$, which is made up of tentative element states $\tilde{a}_n^u(t+1)$ (as indicated in Eq. 5).

$$S^u(t) \rightarrow \tilde{S}^u(t+1) \; with \; P(\tilde{a}_n^u(t+1) = a_n^u(t)) = 1 - p \; and \; n \in S^u. \tag{6}$$

The firm then *tests* if the new configuration $\tilde{S}^u(t+1)$ constitutes an improvement in fitness relative to $S^u(t)$. As agents in the cluster act simultaneously and cannot be fully informed about the future activities of all others, their best bet for assessing the new configuration is to test whether it would have improved the fitness in the context of the last known configuration of others' activities. As a result, agents test the new configuration while assuming that other agents in the cluster will not change their configurations. This aspect implies that test activity aims at determining the fitness of the proposed configuration using the agents' new element states $\tilde{a}_n^u(t+1)$ and the past states $a_n(t)$ for those elements controlled by firms in other cluster segments.[5]

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[4] In the subsequent description of the model, preliminary values will be distinguished by $\tilde{S}, \tilde{w}$ *and* ã.

[5] For detail on the determination of the $a_n(t)$ values, see section 2.2.3.

$$\hat{a}_n(t+1) = \begin{cases} \tilde{a}_n^u(t+1), & n \in S(u) \\ a_n(t), & n \notin S(u) \end{cases} \quad (7)$$

The result of test activity is thus an expected fitness value for the elements in the proposed configuration $\tilde{w}(\hat{a}_n(t+1))$. Taken together, they yield an expected fitness value $\tilde{w}(\tilde{S}^u(t+1))$ for the proposed configuration $\tilde{S}^u$, which is based on the element states given by (7). This fitness is expected as changes by agents located in the other segments might have an unexpected impact on the fitness of the new configuration. It is argued here, that test activity in both types of clusters is based on the fitness of each firm, i.e. firms test, whether the proposed configuration improves the average fitness of the n elements within their production segment:

$$\tilde{w}(\tilde{S}^u(t+1)) = \frac{1}{S^u} \sum_{n \in S^u} \tilde{w}(\hat{a}_n(t+1)). \quad (8)$$

Agents then *select* a new configuration if its expected fitness exceeds that of the previous configuration $w(S^u(t))$, i.e. $\tilde{S}^u(t+1)$ is selected as the new agent configuration (made up of the new element states $a_n^u(t+1)$).

$$S^u(t+1) = \begin{cases} \mathrm{S^u(t)} & \text{for } \tilde{\mathrm{w}}(\tilde{\mathrm{S}}^{\mathrm{u}}(\mathrm{t}+1)) \leq \mathrm{w}(\mathrm{S^u(t)}) \\ \tilde{\mathrm{S}}^{\mathrm{u}}(\mathrm{t}+1) & \text{for } \tilde{\mathrm{w}}(\tilde{\mathrm{S}}^{\mathrm{u}}(\mathrm{t}+1)) > w(S^u(t)) \end{cases} \quad (9)$$

2.3.2 Group and cluster dynamics

The configurations discovered by agent search, test and selection activity are then proposed as representatives of their respective groups. In the model, groups consist of all agents (firms) located in the same production segment. For each group, the agent with the configuration offering the highest expected fitness for the entire production process is chosen (10). This mirros the diffusion of best practice in clusters (Maskell 2001) where agents in the same stage of the value chain can easily observe and imitate any better solution that their competitors have encountered. The configuration of each production segment *S* at time *t*+1 is therefore determined by:

$$S(t+1) = \arg\max_{S^u(t+1)} \sum_{n \in S} \tilde{w}(a_n^u(t+1)), u \text{ } with \text{ } S^u \in S. \quad (10)$$

Taking all chosen agent configurations $S(t+1)$ together then yields the actual fitness of each element state $w(a_n(t+1))$. These fitness values can then be aggregated to determine the fitness of the cluster ($W(M_{t+1})$) as well as that of its agent groups (individual production segments, $w(S_i(t+1))$:

$$W(M(t+1)) = \frac{1}{N} \sum_{i=1}^{N} w(a_n(t+1)) \quad (11)$$

and

$$w(S_i(t+1)) = \frac{1}{S}\sum_{n\in S_i} w(a_n(t+1)). \qquad (12)$$

For the analysis, both average fitness (mirroring the performance of adjustment process) and the standard deviation (indicating their stability) were gathered.

2.4 Simulation setup

Within the simulation, the three model parameters are set as follows. Regarding the *production process*, there are M=24 activities in the model. Depending on the degree of division of labour, two different setups are distinguished. The integrated, large firm cluster (Boston 128 type) and the decentralised, networked small enterprise (Silicon Valley type) one. The different cluster types are summarised in table 1.

Table 1: Disintegrated versus integrated clusters

Label	Agents	Segments
Dec 2	p=0.50; Ag=2	r=4; n=6
Dec 4	p=0.50; Ag=4	r=4; n=6
Int 2	p=0.25; Ag=2	r=2; n=12

In the *integrated* cluster, there are r=2 production segments S, comprising n=12 elements each. In the *decentralised* cluster, r=4 and each segment S comprises n=6 elements. Firms in either type of cluster exhibit the same level of search activity, i.e. p is set in such a way that Silicon Valley and Boston 128 firms change the same number of elements in each search step. The configuration chosen here was such that each firm changes the states of three elements on average which corresponds to p=0.5 for Silcon Valley firms controlling n=6 elements and p=0.25 for Boston 128 firms controlling n=12 elements. The final aspect that differs between decentalised and integrated clusters is the number of firms in each production segment. The analysis includes integrated and decentralised clusters with two firms per production segment (labelled *Dec 2* and *Int 2*). To account for the usually greater number of firms found in decentralised clusters, the model also introduces one setup in which the decentralised Silicon Valley type cluster hosts twice the number of firms per segment as the integrated Boston 128 one (*Dec 4*).

Figure 1: Element interdependence

	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	N21	N22	N23	N24
w_1	-	x	x	x																				
w_2	x	-	x	x																				
w_3	x	x	-	x																				
w_4	x	x	x	-																				
w_5					-	x	***x***	***x***																
w_6					x	-	***x***	***x***																
w_7					***x***	***x***	-	x																
w_8					***x***	***x***	x	-																
w_9									-	x	x	x												
w_{10}									x	-	x	x												
w_{11}									x	x	-	x												
w_{12}									x	x	x	-												
w_{13}													-	x	x	x								
w_{14}													x	-	x	x								
w_{15}													x	x	-	x								
w_{16}													x	x	x	-								
w_{17}																	-	x	***x***	***x***				
w_{18}																	x	-	***x***	***x***				
w_{19}																	***x***	***x***	-	x				
w_{20}																	***x***	***x***	x	-				
w_{21}																					-	x	x	x
w_{22}																					x	-	x	x
w_{23}																					x	x	-	x
w_{24}																					x	x	x	-
	Group 1						Group 2						Group 3						Group 4					

The interdependence of elements in the production process (*K*) is gradually increased, assuming a block distribution of interdependencies. This means that elements in blocks of length K are reciprocally interdependent. This is illustrated in figure 1 for the decentralised cluster and *K*=4.

The environment's volatility is distinguished according to the extent of external perturbations as well as their frequency. There are *shock* environments in which the entire fitness landscape changes after a certain time as well as *disturbance* environments, where only part of the landscape is altered. In addition, the time between perturbations differs. In *fast* environments, it equals 300 simulation steps and in *slow* environments, 600 steps precede any perturbation. Four environmental constellations are thus investigated: Slow and fast shock environments as well as slow and fast disturbance environments.

3 Results

In the *N*/*K* model, the role of decentralisation for adaptability is conditional on three aspects: Agent search space (determined by the number of elements in the production segment), agent numbers and the degree of inter-agent externalities. Firms in a Silicon Valley type cluster have been argued to control and search over *n*=6 elements as compared to the *n*=12 elements pertaining to firms in the Boston 128 case. As a result, the search space for firms in decentralised clusters is smaller than for more integrated organisations. This increases the speed of search, implying that decentralisation might enable firms to react faster to changes in their environment.

Agent numbers, i.e. the number of firms in each production segment also influences the speed of search processes by determining how many new configurations of each production segment are tried in one simulation step. As a consequence, clusters with more agents per production segment are likely to perform better and faster in adjusting to change. These features would be particularly beneficial in environments where change is fast:

Proposition 1: Environments in which change is fast will benefit decentralised clusters hosting many firms.

At the same time, decentralisation can be harmful to adaptability as it implies greater interdependence between agents. This means that agents in decentralised clusters have to relie more on the activities of others to achieve good results. As clusters lack a central authority, there is no mechanism to ensure that firm activities lead to collectively optimal results Dosi, Levinthal and Marengo (2003). As a result, the greater speed of search in decentralised clusters could come at the expense of aggregate performance. Inter-agent interdependencies would be a characteristic of very complex (interdependent) production processes, implying that:

Proposition 2: Very complex (interdependent) production processes favour more integrated cluster types.

Decentralised Silicon Valley cluster types will thus offer benefits compared to integrated Boston 128 ones if environmental change is fast and if the complexity of the production process does not become too extreme. The following two sections elaborate on these propositions by presenting the simulation results for shock and disturbance environments.

3.1 Shock environments

As is apparent from tables 2 and 3, Silicon Valley type clusters (Dec 2 and Dec 4) can only outperform the Boston 128 type (Int 2) under specific conditions. Environmental change events have to happen fast, the production process has to be of limited complexity ($K \leq 10$) and the decentralised cluster has to host more agents per production segment (Dec 4) than the integrated one (Int 2). Slow environmental change, high product complexity or identical agent numbers in turn represent situations in which integrated production networks are more adaptable.

The findings for shock environments are very much in line with the propositions developed in section 3. With growing complexity of the production process, integration begins to pay as a means to reduce inter-agent interdependence and therefore the extent of mutual disturbance, which is also reflected in the lower standard deviation for the *Int 2* case as compared to *Dec 2* and *Dec 4* (see also table 3). In situations with limited inter-agent interdependence, decentralised clusters with more firms however out-perform their integrated counterparts due to their speed advantage in search activity. This aspect is also reflected in the results for different degrees of environmental volatility. If shocks in the cluster's environment occur fast, decentralised networks outperform integrated ones for limited complexity levels ($K \leq 10$). If the time between shocks is longer, i.e. if they happen more slowly, the relative performance of disintegrated versus integrated production networks is reversed.[6] Alongside the established finding relating the benefits of decentralisation to production process complexity and modularity (decomposability) Ethiraj and Levinthal (2004*b*); Langlois (2002), as well as environmental conditions, the present model however highlights a third condition favouring decentralisation: The number of agents in the production network.

Table 2: Shock environment - fast and slow

Fast	4	5	7	8	9	10	11	12
Dec 2	0.71570	0.71516	0.69822	0.67744	0.69240	0.65951	0.63535	0.65047
Dec 4	0.72368	0.72281	0.71882	0.71162	0.71793	0.69081	0.66965	0.67719
Int 2	0.72255	0.71565	0.71535	0.71081	0.70557	0.70770	0.70976	0.71881
Slow	4	5	7	8	9	10	11	12
Dec 2	0.72046	0.72029	0.70612	0.68471	0.70012	0.66841	0.64238	0.66165

[6] The only exception being the case of K=9, where the fitness of Dec 4 is greater than that of Int 2.

Dec 4	0.72596	0.72679	0.72453	0.71870	0.72381	0.70066	0.68341	0.69031
Int 2	0.73383	0.72847	0.72933	0.72425	0.71934	0.72311	0.72634	0.73418

Table 3: Shock environment - fast and slow

Fast	4	5	7	8	9	10	11	12
Dec 2	0.00469	0.00512	0.00584	0.00680	0.00644	0.00723	0.00747	0.00693
Dec 4	0.00456	0.00492	0.00546	0.00623	0.00610	0.00718	0.00732	0.00691
Int 2	0.00518	0.00528	0.00535	0.00538	0.00542	0.00542	0.00526	0.00509
Slow	4	5	7	8	9	10	11	12
Dec 2	0.00343	0.00392	0.00496	0.00608	0.00574	0.00665	0.00707	0.00642
Dec 4	0.00330	0.00367	0.00430	0.00522	0.00501	0.00623	0.00661	0.00621
Int 2	0.00386	0.00407	0.00427	0.00432	0.00437	0.00443	0.00425	0.00399

3.2 Disturbance environments

The relative performance of Silicon Valley versus Boston 128 type clusters is somewhat different when they are exposed to disturbance environments. Again, the Silicon Valley type (Dec 2 and Dec 4) is more adjustable than the integrated Boston 128 one unless interdependence becomes too extreme ($K \leq 10$). Unlike the findings reported in the previous section, more time between perturbation events does not alter this relative performance (see tables 4 and 5).

Table 4: Disturbance environment - fast and slow

Fast	4	5	7	8	9	10	11	12
Dec 2	0.72387	0.72555	0.70812	0.68464	0.70515	0.66651	0.64064	0.65779
Dec 4	0.73159	0.73445	0.72702	0.71470	0.72874	0.70641	0.68385	0.68709
Int 2	0.72944	0.71724	0.71137	0.69122	0.69746	0.71093	0.70947	0.71827
Slow	4	5	7	8	9	10	11	12
Dec 2	0.72967	0.71443	0.70946	0.68856	0.70492	0.67644	0.64826	0.66452
Dec 4	0.73234	0.72295	0.72445	0.72262	0.72715	0.71074	0.68752	0.69466
Int 2	0.73655	0.71968	0.71426	0.70529	0.70172	0.71408	0.71845	0.72786

Table 5: Disturbance environment - fast and slow

Fast	4	5	7	8	9	10	11	12
Dec 2	0.03625	0.03581	0.04856	0.06464	0.05695	0.06722	0.07276	0.06396
Dec 4	0.03748	0.03161	0.04008	0.05100	0.04653	0.05791	0.06847	0.05961
Int 2	0.03363	0.03544	0.04357	0.04175	0.04328	0.04221	0.03923	0.02783
Slow	4	5	7	8	9	10	11	12
Dec 2	0.03267	0.03578	0.04891	0.06206	0.05666	0.06921	0.07560	0.06632
Dec 4	0.03107	0.03258	0.03741	0.04571	0.04488	0.06156	0.06528	0.05861
Int 2	0.02921	0.03633	0.03923	0.04510	0.04426	0.04160	0.03475	0.02626

An interesting difference between decentralised and integrated clusters in adjustment to shock versus disturbance environments regards the performance of producer groups, i.e. the performance among firms in one stage of the value chain. While producer groups in both cluster types exhibit similar fitness values (see table 6 for the case of fast distrubance environments), the stability of adjustment processes at the group level is a lot lower for decentralised clusters. This implies that the risk of failure by individual actors is higher for decentralised production networks than for more integrated ones, a result in line with the observations made by Saxenian (1994). As a result, one would argue that alongside greater agent numbers and appropriate degrees of complexity in production processes, decentralised clusters adjusting to disturbance environments would require strong startup dynamics to compensate for individiual firm failue.[7]

[7]The same finding emerged in slow disturbance environments but not for shock environments (results not reported here).

Table 6: Group performance in fast disturbance environments

Fitness	Group	4	5	7	8	9	10	11	12
Dec 4	Group 1	0.7401	0.7480	0.7732	0.7357	0.7227	0.7033	0.6877	0.6893
	Group 2	0.7302	0.7239	0.7088	0.6946	0.6991	0.6895	0.6806	0.6897
	Group 3	0.7207	0.7306	0.7182	0.6954	0.7226	0.7025	0.6914	0.6822
	Group 4	0.7354	0.7353	0.7079	0.7332	0.7706	0.7303	0.6757	0.6871
Int 2	Group 1	0.7360	0.7158	0.7117	0.6910	0.7009	0.7120	0.7147	0.7178
	Group 2	0.7229	0.7187	0.7110	0.6915	0.6940	0.7099	0.7043	0.7188
Stability	**Group**	**4**	**5**	**7**	**8**	**9**	**10**	**11**	**12**
Dec 4	Group 1	0.0655	0.0608	0.0650	0.0747	0.0862	0.0984	0.1047	0.1036
	Group 2	0.0675	0.0692	0.0786	0.0914	0.0890	0.0965	0.1037	0.1017
	Group 3	0.0730	0.0734	0.0798	0.0931	0.0859	0.0987	0.1123	0.1020
	Group 4	0.0689	0.0738	0.0724	0.0831	0.0517	0.0751	0.0979	0.1041
Int 2	Group 1	0.0443	0.0518	0.0545	0.0559	0.0534	0.0490	0.0469	0.0404
	Group 2	0.0437	0.0492	0.0521	0.0552	0.0579	0.0573	0.0557	0.0396

Summing up, it can be said that the effects of environmental volatility and production process complexity map out as indicated in propositions 1 and 2: Environmental volatility and limited complexity benefits decentralised cluster types with more firms, whereas integrated clusters perform better in situations with less environmental volatility (especially regarding the frequency of change events) and greater production process complexity. Moreover, disturbance environments exhibit strong fluctuations in adjustment processes for producer groups, which increase the risk of individual firm failure.

4 Discussion

The present paper set out to study the role of decentralisation of production networks for their adjustability to changes in the greater economic environment. Building on the case of production networks in industrial clusters and existing empirical evidence of the Silicon Valley - Boston 128 computing clusters, a model was developed that was able to account for stylised facts regarding the dynamics of clusters and their constituent firms. Through simulation exercises comparing the adjustability of different idealtypical clusters, the model was able to derive conditions under which decentralised networks are more adaptive than integrated ones.

Some of the results presented here echo findings in other areas of research. As is established in the literature on modularity, the extent to which tasks can be separated and allocated to different units in an organisation is also vital when attempting to split a common production process between different firms. In other words, both the degree and the distribution of interdependencies pose a limit on decentralisation. In line with previous empirical and theoretic observations Saxenian (1994); Grabher (1993); Uzzi (1997*b*); Uzzi (1997*a*); Williamson (1991), the model also finds that decentralised networks are usually more adjustable to changing environments than more integrated ones. However, the results found here indicate that it is less the extent of environmental change events (shock versus disturbance) but rather their frequency (slow versus fast) that decides over the benefits to decentralisation.

Finally, the model is able to highlight, that in clusters, the relative advantage of decentalised versus more integrated production networks depends on two additional conditions: Agent numbers as well as startup dynamics. Agent numbers impact on the speed of search in the *N*/*K* model and can therefore compensate for some of the disadvantages of small, networked firm clusters (e.g. regarding inter-agent interdependence). Moreover, the greater instability of adjustment to disturbances at the level of producer groups indicates that decentralised, Silicon Valley type clusters require strong startup dynamics to compensate for a higher risk of firm failures. While both conditions were met by the Silicon Valley, they could explain why not all decentralised, small-firm clusters were able to out-compete their more integrated counterparts.

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