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Simulation

Values of all models parameters are presented in the Appendix. Crucial for our simulation of path-dependence is a form of the transformation of routines into the set of product characteristics $F(r)$, productivity of capital $A(r)$ and unit cost of production $V(r)$ (equation (4), see also Figure 6).

The functions of routines transformation into the technical characteristics, productivity of capital $A(r)$, and variable cost of production $V(r)$ are assumed to be as simple as possible but with care to reflect reality at the accepted level. In real processes number of routines is very large one. The number of technical characteristics is (probably) much smaller but also can be large one. Beside constraints related to available computer memory the numbers of routines and technical characteristics simulated in the model can be really very large but from the point of view of possibility to analyse and to visualise simulation results it is necessary to assume reasonable small number of these parameters. In the presented characteristics we assume that there are 10 routines and two technical characteristics.

The relationship between routines and technical characteristics are assumed to be linear:

$$z_d(r) = c_{d0} + \sum_i c_{di} r_i \quad \text{for } d = 1, 2$$

Values of c_{di} are assumed to be constant for all simulation runs (see Table 1) and for different assumed initial values of technical characteristics z_d a relevant values of c_{d0} are calculated.

To assure that values of unit cost of production and productivity of capital are positive we assume the modified linear transformation of routines into those variables, namely

$$V(r) = v_0 e^{-b\left|\sum_i v_i r_i\right|}$$

$$A(r) = a_0 \left|\sum_i a_i r_i\right|^c$$

Similarly values of a_i and v_i are assumed to be constant in all simulation runs and values of a_0 and v_0 are calculated to assure the assumed initial values of unit cost of production and productivity of capital.

The number of routines is five times greater then the number of technical characteristics. The values of transformation parameters are selected intentionally to model, mentioned earlier (Fig. 7), the poligeny and pleiotropy effects.

Table 1. The values of parameters of routines' transformations.

	v_i	a_i	c_{1i}	c_{2i}
r_1	0	-4	0.15	-0.1
r_2	8	0	0.0	0.1
r_3	-8	-3	0.07	0.0
r_4	-5	6	0.06	0.0
r_5	-4	-9	0.05	0.15
r_6	4	3	-0.08	0.1
r_7	1	-5	-0.1	0.1
r_8	0	7	-0.1	-0.1
r_9	-9	5	0.1	-0.1
r_{10}	7	-1	-0.15	0.07

We can see that there are routines influencing the cost, the productivity and the technical characteristics (r_5, r_6, r_7, r_9, and r_{10}), and also routines influencing three or two of those four characteristics. There are also differences in sensitivities of these influences and signs of influences (positive or negative). In general case to improve quality of products performance (measured by technical competitiveness), reduce cost of production and improve productivity of capital it is necessary to modify more then one routine. In most cases modification of a single routine can improve one feature but deteriorate one or two other features (e.g., improvement of technical competitiveness is accompanied with increases of cost of production or diminishes of productivity of capital).

We can see the development of simulated industry as a trajectory in the space of technical characteristics or in the space of routines. Therefore we can try to search for path-dependence properties in both spaces.

Adaptive landscape

An adaptive landscape, described by function $q(z)$ in eq. (5), can have different shapes and it would be interesting to investigate how different class of this function shape modes of evolution. It seems to be rational to assume some regularity of this landscape and it can be viewed similar as Waddington did in his concept of epigenetic landscape (see Fig. 1). The only difference is that in our modelling we think in terms of maximisation of technical competitiveness and Waddington thought about minimisation of misfitness. Therefore instead of valleys and holes we have ridges and peaks. Our adaptive landscape can have different number of peaks, can be dynamical and this peaks can move and change their altitudes. Keeping all this complication im mind, let's start our simulation from relative simple case of stable (not changing in time) two adaptive peaks with different altitudes (see Fig. 7). Coordinates of these two peaks are (15, 20) and (35, 40), and the altitude equal to 1, and 2,5, respectively). Therefore we can say that from technological point of view, products with characteristics close to the second peak are 2.5 times better then products with characteristics close to the first peak.

Let's assume that we start initially from an industry which consists of 12 equal firms placed more close the lower peak. In fact we assume that products produced by initial firms have technical characteristics equal to z_1=5 and z_2=10 (i.e., coordinates of this products are equal to (5, 10)). Technical competitiveness of this products is equal to 0.135, i.e. are roughly seven times worse then the potential products with characteristics close to the first (lower) peak. All firms search for innovation through autonomous research or through imitation of competitors. At the beginning the recrudescence is not acting. What we observe at the first phase of industry development is the finding better products being closer to the first peak. The second peak is so distanced that the probabilities of finding products with characteristics close to the second peak are very low. In the course of time the 'population' of firms will come closer and closer to the first peak. We say that through research process firms search for different inventions which can become innovation if their technological superiority (i.e. higher values of technical competitiveness) is accompanied by acceptable values of economic characteristics (i.e., lower unit cost of production or higher productivity of capital). At any moment of time each firm make decisions of including just founded invention into practice (to become innovation). During that decision all technical and economic factors are taken into account. Sometime it can happen that potential invention is so radical that it is not bale to make modernisation of production (e.g. cost of modernisation exceed the investment abilities of that firm). In such a case the firms continues the 'old' production and concurrently starts the new production of that radical products at smaller scale. We say that the firm is a multi-unit operation. In the course of time the old production is reduced and the new one is expanded.

After few decades of development industry reach the lower peak and (as numerous simulation show) applying only search for new products based on 'mutation' (autonomous research) and imitation, firms are not able to find products with characteristics placed on the second peak. The only possibility is to apply the recrudescence mechanisms (with relatively high probabilities of transposition of routines from latent do active sets of routines). After some period of search for recrudescence a 'solution' (product) placed on the second peak is found. Since that moment it is assumed that the probability of recrudescence become low again and the search is based mainly on 'mutation' and imitation. In the course of time firms produce more and more products with characteristics close to the second peak and concurrently they reduce the 'obsolete' production placed on the first peak.

Naturally products of firms are different and at any moment we observe relatively high heterogeneity of products (measured in terms of unit cost of production, productivity of capital, prices, products characteristics but also heterogeneity in terms of routines applied by each firm). If, at any moment of time, we calculate average values of each characteristics within the population of firms and we trace all those points in the adaptive landscape we obtain the trajectory of industry development (see Figure 7a and 7b, where trajectory of typical industry development is shown). Some other characteristics of development, obtained in that typical simulation run are shown in following figures: price and its diversity (Figures 8), technical competitiveness (Figure 9), competitiveness (Figure 10), unit cost of production (Figure 11), productivity of capital (Figure 12) and average profit to capital and average investment rate (Figure 13). On same figures maximum or minimum of relevant characteristics are also presented – the distance between the average values and the extreme values give hint on products diversity.

This kind of simulation run has been repeated many times (no less then 20 times in all presented simulations). Trajectories of development of 21 simulation runs are presented in Figures 14 (alongside of the adaptive landscape) and Figure 15 (on the background of contour of the adaptive landscape). We can see that there is very small diversity of development in a all simulation runs. All 20 trajectories are very similar. In the first phase all industries more or less gradually approach the first peak along one pathway of change (chreod) and next they move over the valley to the second higher peak.

In Tables 1 and 2 the average values of technical characteristics and ten routines at two moments: in a year 60 (after reaching the first peak) and in 150 (after reaching the second peak), are presented. It is visible that average values of technical characteristics are very close to the coordinates of relevant peaks (i.e., (15,20) in Table 1and (35, 40) in Table2). It can be said that for this simulation conditions industry has strong tendency to develop along one way of change (chreod). It can be interpreted that pathway of change in this simulation runs is predetermined.

Contrary to observations at the technical characteristics space, the pathways of change observed at the routines level are highly heterogeneous. We can trace the pathway of change of routines from year to year but it is very difficult to visualise it in the 10^{th} dimensional space of routines. The average values of routines at years 60 and 150 can give us a hint on the mode of development. We can notice that some of routines are very 'conservative' ones – their values are very close to the initial values. The most conservative seems to be the routine r_{10}, but it can be said also about routines r_1, r_2, and r_7. Average values of routines r_2, r_4, and r_6 are highly different in different runs. But it is interesting that there are clusters (attractor regions) of the routines vectors. Closer observation of detailed simulation results indicate that in each run there is a decisive moment in which random event determines a further evolution at the routine level. To find some better products it is necessary to tune two, three or more routines. Because of higher dimensionality of the routine space the same technical characteristics can be obtained by different sets of routines. Naturally it depends on the transformation function of routines into the technical characteristics and also on the shape of adaptive landscape. We can say that we observe also the path-dependence at the routines level but the heterogeneity of these paths is much higher (as compared to the technical characteristics space). The lock-in is very frequent and very characteristic at the routines level. Very frequently, random events (especially at the beginning phase of industry development and at the phase of placing the population at the local, lower peak) decides on future development of industry.

Let's look more closely at the first run. After reaching the first peak there were 44 firms in the market. The largest firm (no. 6) was two-unit operation (see Figure 16). Some characteristics of the largest firms are presented in Table 3 and their routines values in Table 4. There is relatively high diversity of the unit cost of production and productivity of capital and relatively small diversity in technical competitiveness. Thanks to diversified price the diversity of the competitiveness index is much smaller than the diversity of the technical competitiveness. The firm labelled as 6 (new) in *t*=150 is not the same as the 6 firm in *t*=60. The 'old' firm has been withdrawn from the market in 103 year and the new 6 firm entered the market in 149. We placed that firm in Tables 3 and 4 because in spite of small market share in 150 (only 0.5%) it is the best firm on the market in *t*=150. The largest firm (labelled as 27) is at t=150 a four-unit operation (three modern units manufacturing advanced products with characteristics close to the higher peak and one 'obsolete' unit manufacturing products with characteristics close to the lower peak).

We see (Table 4) that the radical innovation allowing finding products with characteristics placed in the higher peak (see Figure 17, where the two radical innovation found in t=90 are market by red stars in the higher peak and also Figure 18, where the state in the end of simulation is presented) are related to radical modification routines 1, 2 and 5 (Table 5), correlated with moderate modifications of routines 4 and 6. Routines 7, 8, 9 and 10 can be called in this run 'conservative one'.

to be continued