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Structural propagation in a production network with restoring substitution elasticities

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HIGHLIGHTS

- A Cascaded CES production function is examined for modeling industrial production.
- Intra-industrial sequence of processes is emulated from the inter-industrial hierarchy.
- Substitution elasticities are calibrated to restore the two observed equilibrium states.
- Restoring substitution elasticities endogenize the transition of production networks.
- Economic gain of external productivity shock is examined in a dynamical context.

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ABSTRACT

We model an economy-wide production network by cascading binary compounding functions, based on the sequential processing nature of the production activities. As we observe a hierarchy among the intermediate processes spanning the empirical input–output transactions, we utilize a stylized sequence of processes for modeling the intra-sectoral production activities. Under the productivity growth that we measure jointly with the state-restoring elasticity parameters for each sectoral activity, the network of production completely replicates the records of multi-sectoral general equilibrium prices and shares for all factor inputs observed in two temporally distant states. Thereupon, we study propagation of a small exogenous productivity shock onto the structure of production networks by way of hierarchical clustering.

1. Introduction

Given the technological interdependencies among industrial activities, innovation (in terms of productivity shock) in one industry may well produce a propagative feedback effect on the performance of economy-wide production. Previous literature pertaining to the study of innovation propagation has based its theory upon the non-substitution theorem [e.g., 1] that allows one to study under a fixed technological structure while restricting the analyses to changes in the net outputs [e.g., 2,3]. Otherwise, Acemoglu et al. [4] assume Cobb–Douglas production (i.e., unit substitution elasticity) with which the structural transformation is restricted to the extent that the cost-share structures are preserved. To study propagation in regard to potential technological substitutions, however, a potential range of alternative technologies must be known in advance. Nonetheless, empirical estimation of the substitution elasticities [e.g., 5] is elusive, and to this end, the dimension of the working variables has been significantly limited.

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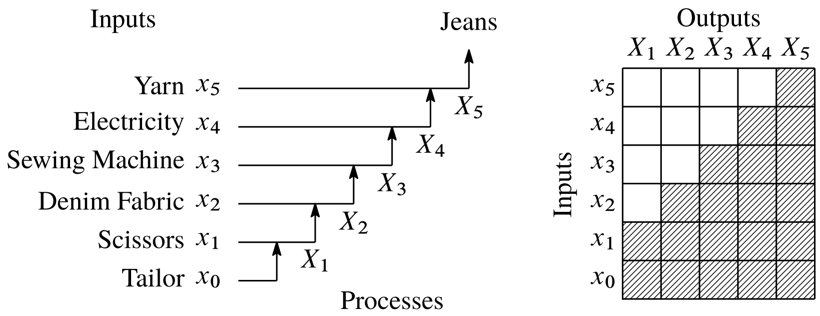

Fig. 1. Serially nested configuration of a production system (left) and the corresponding incidence matrix (right) spanning direct and indirect inputs and intermediate outputs.

In contrast, this study is concerned with the economy-wide propagation of innovation that involves structural transformation with regard to the potential range of technologies among input variables of large (385) dimension. In so doing we model multiple-input production activity by serially nesting (i.e., cascading) binary-input production functions of different substitution elasticities. For each industry (or sector of an economy), the elasticity parameters of the production function are measured jointly with the productivity changes so that the economy-wide production system completely restores monetary and physical inputs in all sectors for two temporally distant equilibrium states. These elasticity parameters are hence called as restoring elasticities.

In the following, we give our rationale for modeling production by nesting binary compounding functions. Consider, say, the manufacture of a pair of jeans. For this case, one needs a sufficient amount of denim fabric, a pair of scissors, a sewing machine, a ball of yarn, some electricity, and a tailor. We know that a pair of jeans will not fall into place all at once but rather it is made in a step-by-step fashion: using a pair of scissors and a sewing machine, the fabric is first cut into pieces, then they are sewn together using the yarn with some help from electric power. Production generally involves a series of processes that combine the output of a previous process with another input of production, before handing the output over to the next process.

A production activity can be configured as a tree diagram such as the one shown in Fig. 1 (left). In this example, the production system comprises a series of six inputs $(x_0, x_1, x_2, x_3, x_4, x_5)$, processed in a hierarchical manner, producing five intermediate outputs, $(X_1, X_2, X_3, X_4, X_5)$, by five processes that are nested serially. Naturally, one may be concerned that the denim fabric, for example, is produced by another (satellite) system, and therefore the extended system is inclusive of a parallel nest. Suppose, for simplicity, that denim fabric is produced by a serially nested process of two factor inputs, say, the indigo-dyed wrap and the plain weft threads, (x_6, x_7). Notice that we may always re-configure a production system into a sequence by decomposing the satellite process. In this case, denim fabric is decomposed into a sequence of two inputs (wrap and weft) and a set of cut fabric (i.e., X_2) is, presumably, produced by the sequence (wrap, weft, tailor, scissors), in which case, the sequence of the inputs of the extended system becomes $(x_6, x_7, x_0, x_1, x_3, x_4, x_5)$.[1]

A cascaded configuration of processes can be transcribed into a triangular incidence matrix, as shown in Fig. 1. The shaded intersections represent the direct and indirect inputs and the distribution of outputs, while indirect feedbacks are ruled out for simplicity.[2] A notable feature of this configuration is that every intermediate process constitutes a part in the overall sequence of processes. For instance, the intermediate process that produces output X_3 consists of four direct and indirect inputs, namely, (x_0, x_1, x_2, x_3), that are processed in this sequence. The overall sequence of processes is of the final output X_5, which is $(x_0, x_1, x_2, x_3, x_4, x_5)$, so the intermediate process X_3 obviously constitutes a part in the overall sequence. Thus, the sequence of every intermediate process is knowable by investigating the overall sequence of the triangular incidence matrix.

Our sector-level modeling of cascaded production activities requires the identification of the sequence of inputs (intra-sectoral processes) for all sectors constituting the economy, and for that matter, we utilize the economy-wide inter-sectoral transactions recorded in an input–output table. We note that, if the incidence matrix transcribed from the input–output table is completely triangular, every sector-level sequence of processes becomes known from the sequence of intermediate processes stylized in the triangulated incidence matrix. We hereafter refer to this sequence as the universal processing sequence (UPS). We will find that the input–output incidence matrix of the 2005 Japanese economy is not completely yet not too far from being triangular. From an empirical perspective, we exploit the universal sequence of processes observed through the triangulation of the input–output incidence matrix. Square matrix triangulation [e.g., 6,7] refers to a generic

1 Of course, the weaving process of the threads requires a weaver. Then, the same kind of input (labor) is put into process at different stages (weaving and tailoring). By allowing indirect inputs we may merge these inputs into the lower stage, whence the sequence becomes $(x_0, x_6, x_7, x_1, x_3, x_4, x_5)$.

2 Indirect feedback may be, for example, the case where X_5 is fed back into x_2. We rule this case out because there will be no way of producing the first pair of Jeans to be used as the source of denim fabric.