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A multi-sector growth model with technology diffusion and networks[☆]

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ABSTRACT

This paper adds the standard input–output linkages into a multi-sector endogenous growth model to study the interaction effects between linkages and technology adoption for aggregate productivity and for income per capita. We show that the greater the intensity with which a good is used as input by other sectors, the smaller are the technology adoption lags and the greater is the technology adoption intensity, and thus the greater are the increases of the Total Factor Productivity and of economic growth. Therefore, distinct input–output relationships between sectors explain inter-country income differences. By using OECD data, we then estimate the model for nine developed countries and ten technologies, and confirm our theoretical findings.

1. Introduction

The core of the endogenous growth theory should not be only the production of knowledge but also its diffusion, which is responsible for Total Factor Productivity (TFP) and explains the majority of inter-country differences in per capita output (e.g., Hall and Jones, 1999; Jerzmanowski, 2007). However, since the initial seminal endogenous growth models (Romer, 1990; Grossman and Helpman, 1991; Aghion and Howitt, 1992) until the semi-endogenous growth models (Jones, 1995), the focus of the literature has been on only the production of knowledge. Given that over time the empirical literature has presented evidence more supportive of the endogenous growth models than of semi-endogenous growth (e.g., Dinopoulos and Thompson, 2000; Laincz and Peretto, 2006; Madsen, 2008; Ang and Madsen, 2015), a new wave of theoretical models has recovered the endogeneous growth result (e.g., Peretto, 1998; Howitt, 1999; Acemoglu, 1998, 2002), and these increasingly highlight knowledge diffusion (e.g., Parente and Prescott, 1994; Basu and Weil, 1998; Comin and Hobijn, 2010).

Concomitantly, an increasing intensification of inter-sector and inter-firm relationships is also observed over time (e.g., Hirschman, 1958; Bartelme and Gorodnichenko, 2015), and this intensification of linkages, reflected in the increased complexity of the production network structure (i.e., in the input–output relationships), was initially neglected by the theoretical growth models. However, some recent studies have shown that: (i) social networks affect the diffusion of communication technologies (e.g., Jackson, 2011); and (ii) the network structure significantly affects the propagation of idiosyncratic shocks (e.g., Acemoglu et al., 2012). Therefore, we can expect that inter-sector network affects the technology diffusion and, consequently, the economic growth.

In fact, the productivity gains reached by modern economies are intrinsically connected with the input–output linkages through convoluted networks, as a result of increasing specialization. The increasing linkages favor learning and knowledge diffusion, reducing the adoption costs and accelerating technology diffusion. For example, the learning and knowledge effects permitted by the input–output linkages were determinant in the acceleration of the diffusion of Information and Communication Technologies (ICT), which, in turn, were important to increase the aggregate productivity. In addition to the previous *learning channel*, the input–output linkages also allow productivity gains in one sector to spread to other sectors due to multiplier effect, which relies on both the supply-side connections of the sector and the intensity with which its output is used as intermediate input in the other sectors (*multiplier channel*). Hence, due to the size of the multiplier, the same productivity increase in different sectors will have distinct effects on aggregate productivity, and on the acceleration and the intensity of the technology adoption.

It is not surprising that the literature in development economics,

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initiated by Hirschman (1958), has highlighted that inter-sector linkages were crucial for economic development since, in the last instance, they explain cross-country income differences and, consequently, this literature has suggested investments in sectors with the strongest linkages. More recently, there has been a spirited literature on the subject (e.g., Ciccone, 2002; Acemoglu et al., 2007; Jones, 2011, 2013; Bartelme and Gorodnichenko, 2015; Fadinger et al., 2016) that reinforces the role of economic structure for aggregate productivity/income since it studies the relationship between input–output linkages, sectoral productivities, and aggregate productivity/income, by considering intermediate goods and, in the latter two works, also tools from network theory.

Our research is thus motivated by a desire to reconcile the endogenous growth literature with the evidence on the intensification of inter-sector and inter-firm relationships in recent years. Our contribution is part of the new wave of theoretical growth models and emphasizes the inter-sector production linkage effects on technology adoption and the resulting impacts on productivity and income differences across countries. That is, we take advantage of the network concept to propose a model that accommodates the core of endogenous growth models in order to examine how the linkages reflected on the production network affect technology diffusion decisions, which, in turn, help to explain inter-country differences in TFP.

To be more precise, we ask how the production network structure or, in other words, the input–output relationships, explain the inter-country differences in adoption lags, adoption intensity, and income per capita. The adoption lags, usually called *extensive margin*, can be decomposed into the *embodiment effect* and the *variety effect*. The former is related to the time of adopting a new technology: the lower the adoption lags, the higher the increase in productivity since the technology embodied in new production methods is more productive. The latter effect is connected with the increase in the range of production methods (i.e., technology varieties) used: when the adoption lag is large (small), the range of technology varieties used is small (large) and, thus, an increase in the range has a strong (weak) effect on productivity – i.e., there is a diminishing return to the range of technology varieties used. Hence, adoption lags affect the curvature of the path of embodied productivity (e.g., Comin and Hobijn, 2010). In turn, the adoption intensity, usually called *intensive margin*, is associated with the number of units demanded for each technology that depends on its productivity.

To summarize, input–output linkages through convoluted networks favor learning and knowledge diffusion (*learning channel*), reducing the adoption costs and in turn the adoption lags (*extensive margin*). As a result, input–output linkages bring forward the adoption of new technologies, which raises TFP. Furthermore, the adoption of a new technology by a specific sector generates network externalities on TFP through multiplier effects (*multiplier channel*). These externalities are internalized by firms in the sector, raising the profitability of the technology and, thereby, intensify its adoption (*intensive margin*) and reduce its adoption lag (*extensive margin*).

By incorporating the input–output linkages in the endogenous growth literature, we fill a gap in the literature with the argument that inter-sector buyer–supply relationships act, via convoluted networks, as an important role in technology diffusion through the *learning channel*, via the *extensive margin*, and through the *multiplier channel*, via the *extensive margin* and the *intensive margin*.

To answer our research question, we extend the technology diffusion model of Comin and Hobijn (2010), considering the idea present in Long and Plosser (1983) and Jones (2011, 2013) to model the input–output linkages, and following the approach present in Acemoglu et al. (2012) and Fadinger et al. (2016) to model the input–output structure as a network. Thus, in the endogenous economic growth literature tradition, we assume that each intermediate good can be consumed or used by other sectors as a production input. In this way, we account for the inter-connections/linkages between sectors in the input–output matrix, which, using a network approach, we map into a weighted directed network in order to capture the features of the production network structure. As argued above, the network structure establishes links between sectors at the micro level, which, according to empirical evidence, seems to have effects at the macro level.

Traditionally the aggregation of a multi-sector growth model into one sector does not take into account the difference between gross output and value-added output.[2] However, when we correctly find the equivalent one-sector value-added model, the network externalities, dependent on input–output linkages associated with the intermediate-goods composition used by sectors, are reflected in the level of TFP. In this way, as argued above, the more the linkages, the higher the positive effects in TFP due to both the *learning* and the *multiplier channels*. In addition, as our model will demonstrate, the linkage effects on TFP can be described by the production network properties. By further detailing the recent literature relevant to our work, which thus analyzes input–output linkages using a network perspective, we find investigations over effects of the production network structure on aggregate fluctuations (Carvalho, 2014; Acemoglu et al., 2012; Kelly et al., 2013), aggregate productivity (Oberfield, 2013; Bartelme and Gorodnichenko, 2015), sector productivities and country income per worker differences (Fadinger et al., 2016), and international trade (Chaney, 2014). Using a network theory perspective, Carvalho (2014) and Acemoglu et al. (2012) analyze the role of sectoral and idiosyncratic shocks in generating aggregate fluctuations. Oberfield (2013) demonstrates that when the ratio of intermediate goods relative to labor in production is high, star suppliers appear[3] endogenously and aggregate productivity increases. Bartelme and Gorodnichenko (2015) reach an econometric specification from a theoretical model, and find a robust relationship between the strength of sectoral linkages and aggregate productivity. Fadinger et al. (2016) set a multi-sector general equilibrium model to analyze the input–output structure effects on sectoral productivities to explain inter-country aggregate income per worker differences. Finally, Chaney (2014) proposes a model to explain the international network of exporters, showing that the existing network of contacts is crucial to find new partners.

Concerning the theoretical results, we observe that indeed the production network structure explains the cross-country differences in the *extensive margin* (adoption lags), the *intensive margin* (adoption intensity), and income per capita. The effects on the *extensive margin*, which aggregates the *embodiment* and the *variety effects*, comes from both the *learning* and the *multiplier channels*. The effects of these channels, in turn, are governed by the input–output linkages through the network structure. The role of *multiplier channel* is also prominent in the adoption intensity (*intensive margin*) due to the firms' internalization of the input–output linkages through the network structure. Finally, the effects on income per capita can be decomposed into three factors: (i) differences in the *intensive margin*, (ii) differences in the time of technology adoption, and (iii) differences in the production network structure. Since the time of adoption is endogenous, it is also influenced by the production network structure.

In practice, to measure the effects of linkages (or production network structure) we use the network theory and show that the quantification of these effects is captured by the network degree. This degree reflects the intensity with which a sectoral good is used as input by other sectors; usually, the literature calls this definition of network degree "(weighted) outdegree" (e.g., Jackson, 2008), i.e., the average number of trade partners in an economy and the strength of their trade flows, by which the network degree, together with the optimal adoption time, affects the *embodiment* and the *variety effects*, which consequently determine the growth rate of the TFP. Likewise, the input–output

[2] Intermediate consumptions are included in gross output but excluded from value-added output.

[3] A star supplier is an entrepreneur who sells intermediate goods for many other entrepreneurs.