Structural Transformation of Innovation

Diego Comin * Danial Lashkari † Marti Mestieri‡§

February 15, 2019

We develop a multi-sector endogenous growth model in which the direction of innovation across sectors is endogenous. The model provides a theoretical general equilibrium framework for studying the classical demand-pull and technology-push drivers of innovation. A robust prediction is that the rate of growth innovation growth is asymptotically higher in more income-elastic sectors. We test this prediction using the universe of U.S. patents and firm R&D investments for the period 1976-2007. The analysis lends empirical support for the main predictions of the model.

Keywords: Directed Technical Change, Structural Transformation, Nonhomothetic CES preferences.
JEL Classification: E2, O1, O4, O5.

---

*Dartmouth College.
†Boston College.
‡Northwestern University.
§We thank Philippe Aghion and seminar participants at Harvard University, Arizona State University, Yale and the Society for Economic Dynamics for insightful comments. We are also grateful to Kun Li, Enrico Berkes, and Ben Pugsley for help with the data.

1 Introduction

Modern economies go through immense structural transformations as their incomes grow: the shares of manufacturing industries in employment and output dramatically decline, while they continuously rise for services. What are the implications of these transformations for understanding the future of growth? Historically, manufacturing industries have shown the fastest rates of technological growth, have hired the most number of R&D workers, and have created the highest volumes of patents, our best available indicator of innovation. In contrast, service industries are often associated with slow productivity growth and low intensity of innovation activity. These observations have caused concerns about the sustainability of innovation and productivity growth among academics and policy makers.[1] These concerns stem from a view of growth that emphasizes the role of technological possibilities as the key determinants of the direction of innovation. If technological possibilities determine which industries are innovation-intensive and which are not, growth will inevitably slow down when the share of economic activity in the former group falls.

As early as Schmookler (1966), however, economists have noted that, due to the non-rivalry of ideas, there are strong incentives for innovation efforts to shift to sectors with larger market demand. Accordingly, to the extent that consumer preferences act as drivers of sectoral market size, they may also act as determinants of the sectoral intensity of innovation. In particular, changes in consumer income can result in shifts in patterns of consumption across sectors. Indeed, recent work has shown that the income elasticities of goods and services produced by different industries show robust and persistent differences (Aguiar and Bils, 2015), and that these differences explain a major part of the long-run reallocations of output and employment across sectors (Boppart, 2014; Comin et al., 2015). These observations provide us with an alternative view for the future of growth: one in which innovation will follow the patterns of structural transformation, and the pull force of demand will raise the rates of innovation and productivity growth in highly income elastic sectors such as services.

In this paper, we study how demand nonhomotheticity and technological possibilieis together shape, first, cross-sectoral variations in market size and, second, the sectoral direction of innovation. We first empirically document that the income elasticities of the outputs of US industries significantly correlate with the rates of growth of patenting and R&D expenditure, as proxies for the output and inputs of innova-

[1] Baumol (1967) famously coined the term "cost disease" to describe a chronic problem of the personal services industry that limits the potential for productivity growth in this sector. More recently, **?** has forcefully argued that the main innovations driving the productivity growth of the manufacturing sector in the 20th century were unique to this era and will not be matched by the more recent innovations in the information and telecommunication industries (see also The Economist's special issue **?**). **?** discusses the close connection between the phenomenon of structural transformation and **?**'s projections about the future of growth.

tion. For this exercise, we use income elasticity estimates that Aguiar and Bils (2015) have obtained using household-level Consumption Expenditure Survey (CEX) data in the US. We further develop a multi-sector model of endogenous growth with nonhomothetic demand and persistent variations in relative income elasticities of sectoral outputs. We find that for, a general class of innovation possibilities frontiers, the income elasticities of sectoral outputs ultimately determine technological growth across industries. The asymptotic equilibrium paths of our economy give rise to the types of correlations that we empirically document in the paper.

To see the core mechanism of our theory and to better appreciate potential interactions between the pull force of demand and push force of technology, consider a static closed economy with two sectors: services (s) and manufacturing (m). Relative output of the two sectors Y_s/Y_m equals the relative demand, which in general depends both on relative prices (P_s/P_m) and income (real consumption C_{tot}). Equalization of the marginal product of productive factors imply that relative sectoral prices (negatively) depend on the relative states of technologies (N_s/N_m) in the two sector. We can show these relationships as

$$\frac{Y_s}{Y_m} = \mathfrak{D}\left(\frac{P_s}{P_m}; C_{tot}\right) \qquad \text{and} \qquad \frac{P_s}{P_m} = \mathfrak{P}\left(\frac{N_s}{N_m}\right).$$

A body of evidence shows that broad categories of goods are gross complements; therefore, the relative expenditure of households $\mathfrak{D}$ is increasing in relative prices P_s/P_m. Together, these demand-side relations suggest relative output is negatively related to relative sectoral technologies. In addition, we can capture the forces of technological possibilities through an innovation supply function

$$\frac{N_s}{N_m} = \mathfrak{T}\left(\frac{Y_s}{Y_m}\right),$$

that shows how relative technology may (positively) respond to the relative size of output and demand. Substituting for the relative prices and intersecting supply and demand, the model endogenizes equilibrium technology (N_s^*/N_m^*) as a function of income C_{tot}. Figure 1 shows how a rise in income C_{tot} affects the equilibrium bias of technology when sector s is more income elastic relative to m. So long as the market size elasticity of the supply of innovation exceeds zero, as income rises the relative state of technology improves in sector s.

Our theory shows how the core mechanism of this static model generalizes to a dynamic setting, and endogenously determines both the *rates of growth* and the levels of technology in an infinite-horizon multisector growth model.[2] We use nonhomothetic

[2]In this sense, our model can be distinguished from theories of factor-biased technical change (Acemoglu, 2002, 2007), in which sectors reach endogenously different levels of technologies, but still

CES preferences (Hanoch, 1975; Comin et al., 2015) to account for variations in the income elasticity of sectoral outputs and formulate the pull forces in demand $\mathfrak{D}$. We assume that entrepreneurs innovate to create novel sector-specific varieties, and that the masses of these varieties determine the states of sectoral technologies in a Romer-style setting. We account for the push forces in our formulation of $\mathfrak{T}$ through heterogeneous costs of innovation for different sectors and allow for intersectoral knowledge spillovers.

Along the equilibrium path of our model, two conditions fully characterize the allocation of sectoral innovation, offering simple and intuitive expressions for their dynamics. First, the entrepreneurial arbitrage condition, or simply the free entry condition, equates the value of entry across sectors. This implies that the productivity of R&D (in creating new varieties) and the value of each new variety are inversely related across sectors. Second, the R&D investment arbitrage equation equates the return to investing in the value of monopoly assets across different sectors. This implies that the sum of growth in value of monopolies and their dividend to value ratios are equalized across sectors. Together, these two conditions imply that the allocation of R&D at any point in time depends on two distinct distributions across sectors: the distribution of (production) market size, and the distribution of (knowledge) asset values. The distribution of market size captures the role of demand-side pull forces, and the distribution of asset values captures that of technology-side push forces. The allocation of R&D workers across sectors is given by a linear combination of these two distributions at any point in time.

We further characterize the asymptotic rates of technological growth for different sectors, along equilibrium paths that converge to a constant rate of growth in real income. We find that relative income elasticities asymptotically pin down both the relative shares of R&D investments and the relative rates of technological growth across sectors. Sectors that produce more income elastic goods asymptotically grow fasters in terms of innovation and productivity. We show that these asymptotic results explain the empirical regularities that we document using firm patenting and R&D expenditure, as proxies for the growth of innovation across sectors. In Appendix **??**, we show that our asymptotic results generalize to a broad class of potential patterns of inter-industry knowledge spillovers.[3]

Our paper contributes to a literature that investigates the determinants of the cross-industry variations in innovation activity. This literature in particular has attempted

grow at the same rates. See below for further discussions of the distinctions between the two models.

[3] We also show that the predictions of our theory generalize to alternative formulations of the process of innovation and endogenous growth. While we present the theory in the main paper based on an expanding varieties model to simplify the exposition, Appendix **??** shows that all of our main results also generalize to a Schumpeterian model of innovation and growth.

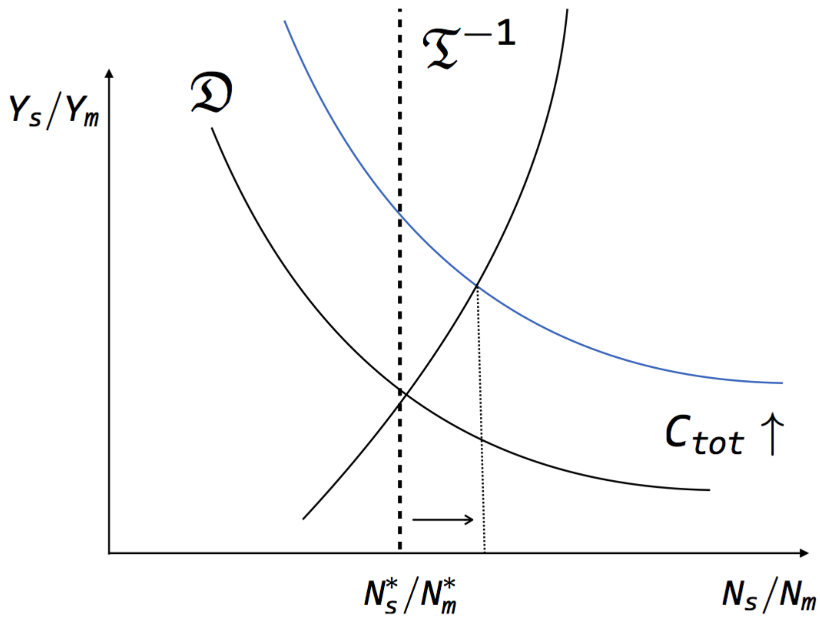

Figure 1: Determination of relative technologies in a static two-sector model of endogenous growth and nonhomothetic demand. The $\mathfrak{D}$ curve shows the relative sectoral consumer demand, and the $\mathfrak{T}^{-1}$ curve the relative supply of innovation. So long as the innovation supply function is not perfectly inelastic (the dashed line), when real income C_{tot} grows, it shifts up the relative demand for the income elastic sector s, and the equilibrium level of relative technology shifts to the right.

to determine whether the ultimate driver of innovation across industries is the incentive pull of the size of demand or the push force of technological possibilities. A number of early and groundbreaking studies documented an industry-level relationship between market size and innovation (Griliches and Schmookler, 1963; Scherer, 1982). However, these studies did not rely on a general equilibrium framework and were therefore marred with conceptual issues. For instance, the empirical exercise favored in this literature, which consisted of correlating patents (or other measures of innovation) with sectoral outputs, did not account for the potential reverse causality between innovation and market size. In particular, the size of output is shaped by sectoral prices, which in turn reflect the state of sectoral technologies. Despite some further work in the literature (Pakes and Schankerman, 1984; Cohen, 2010), we still lack a theoretical framework to study the interactions between technology and demand in shaping the sectoral direction of innovation in a general equilibrium setting. More recent theoretical work on growth has largely disregarded the empirical regularities documented by this literature. In particular, even though the endogenous growth theory (Romer, 1986, 1990; Grossman and Helpman, 1990) relies on Schmookler's concept of private, profit-driven R&D, but it has abandoned the question of sectoral bias of innovation in favor of single sector models that study aggregate outcomes.

We argue that the gap in the literature on the sectoral direction of innovation in part stems from the lack of demand systems that feature persistent heterogeneity in income elasticities. In this paper, we employ nonhomothetic CES preferences, introduced first by Hanoch (1975) and Sato (1975) and recently used by Comin et al. (2015), to address the difficulty in formulating such demand systems.[4] We focus on constant growth paths where persistent variations in income elasticities, in combination with income growth, imply large variations in market sizes across sectors.[5]

Our theory shares some of the core features of the theory of factor-biased technical change (Acemoglu, 2002, 2007), but is also distinct in important ways. First, Acemoglu (2002) focuses on the bias of innovation toward different factors of production, e.g., skilled versus non-skilled labor, in a two-factor and one-good model of growth. Instead, we focus on the direction of innovation across different industries in a single-factor and multiple-good model of growth. In Acemoglu's model, the underlying heterogeneity stems from the variations in the stocks (endowments) of factors of production.[6] In contrast, the underlying heterogeneity in our model is driven by the (plausibly exogenous) differences in the income elasticity of goods and services produced by different sectors. There is no a priori reason to believe that factor intensities across different sectors necessarily produce biases similar to those we derive here based on income elasticities.[7] Even if such correlations exist, the mechanism identified in our paper would operate distinctly from that of a theory of factor-biased technical change.

On the empirical side, very few papers have attempted to carefully identify the response of innovation to market size. The few exceptions are Acemoglu and Linn (2004), who report in a study of pharmaceutical industry a response in terms of the number of drugs developed, but not for patents (see also Cerda, 2007; **?**). More recently, **?** provides evidence that product innovations are disproportionately biased toward goods consumed by high-income households, using barcode-level scanner data from the US retail sector.

The paper is organized as follows. Section **??** discusses our empirical exercise. Section **??** presents the model, and Section 2 concludes the paper. Most proofs are contained in Appendix **??**.

---

[4]We note another recent theory that has studied sectoral composition of innovation in a two-sector model for the production of goods and services (Boppart and Weiss, 2013).

[5]Relatedly, previous work in the field of industrial organizations (see, e.g., Cohen et al., 1987) has used variations in the income elasticity of demand to account for variations in R&D intensity of firms.

[6]We note that, importantly, Acemoglu (2002) abstracts away from factor accumulation in his theory of factor-biased technical change, assuming exogenous and constant factor endowment across the economy. It is likely that accounting for factor accumulation may modify some of the predictions of the benchmark theory of factor-biased technical change.

[7]We note that a recent paper by Caron et al. (2014) in fact documents a correlation between skill intensity and income elasticity of demand for outputs across sectors, based on trade flows data.

2 Conclusion

In this paper, we construct the first theory that endogenously determines the direction of innovation across sectors that produce goods with robustly heterogenous income elasticities. Our theory provides a framework to study the general equilibrium interactions between demand-pull and technology-push forces in determining the equilibrium rates of innovation and productivity growth across industries. We provide simple and intuitive characterizations for the evolution of R&D intensity across sectors. In the model, the asymptotic rates of innovation and productivity growth are pinned down by the income elasticities of sectoral outputs. We show that the rates of growth of R&D expenditure and patents in the US show sizable correlations with the income elasticities of their outputs, estimated using micro-level household consumption surveys.

References

Acemoglu, Daron, "Directed Technical Change," *Review of Economic Studies*, 2002, *69* (4), 781–809. 3, 6

_ , "Equilibrium bias of technology," *Econometrica*, 2007, *75* (5), 1371–1409. 3, 6

_ **and Joshua Linn**, "Market size in innovation: theory and evidence from the pharmaceutical industry," *Quarterly Journal of Economics*, 2004, *119* (3), 1049–1090. 6

Aguiar, Mark and M Bils, "Has Consumption Inequality Mirrored Income Inequality?," *American Economic Review*, 2015, *105* (9), 2725–2756. 2, 3

Baumol, William J, "Macroeconomics of unbalanced growth: the anatomy of urban crisis," *American Economic Review*, 1967, *57* (3), 415–426. 2

Boppart, Timo, "Structural change and the Kaldor facts in a growth model with relative price effects and non-Gorman preferences," *Econometrica*, 2014, *82* (6), 2167–2196. 2

_ **and Franziska J Weiss**, "Non-homothetic preferences and industry directed technical change," 2013, (June), 1–45. 6

Caron, Justin, Thibault Fally, and James R Markusen, "Internationl trade puzzles: a solution linking production and preferences," *Quarterly Journal of Economics*, 2014, *129* (3), 1501–1552. 6

Cerda, Rodrigo A., "Endogenous innovations in the pharmaceutical industry," *Journal of Evolutionary Economics*, 2007, *17* (4), 473–515. 6

Cohen, Wesley M., "Fifty years of empirical studies of innovative activity and performance," in "Handbook of the Economics of Innovation," 1 ed., Vol. 1, Elsevier B.V., 2010, pp. 129–213. 5

Cohen, Wesley M, Richard C Levin, and David C Mowery, "Firm size and R&D intensity: a re-examination," *Journal of Industrial Economics*, 1987, *34* (2), 217–223. 6

Comin, Diego, Danial Lashkari, and Marti Mestieri, "Structural change with long-run income and price effects," 2015. 2, 4, 6

Griliches, Zvi and Jacob Schmookler, "Inventing and maximizing," *American Economic Review*, 1963, *57* (3), 415–426. 5

Grossman, Gene M and Elhanan Helpman, "Trade, innovation, and growth," *American Economic Review*, feb 1990, *151* (3712), 867–8. 5

Hanoch, Giora, "Production and Demand Models with Direct or Indirect Implicit Additivity," *Econometrica*, 1975, *43* (3), 395–419. 4, 6

Pakes, Ariel and Mark Schankerman, "An exploration into the determinants of research intensity," in Zvi Griliches, ed., *R&D, Patents, and Productivity*, Vol. I, University of Chicago Press, 1984, pp. 209–232. 5

Romer, Paul M, "Increasing Returns and Long-Run Growth," *Journal of Political Economy*, 1986, *94* (5), 1002–1037. 5

Romer, Paul M., "Endogenous Technological Change," *Journal of Political Economy*, 1990, *98* (S5), S71. 5

Sato, Ryuzo, "The Most General Class of CES Functions," *Econometrica*, 1975, *43* (5), 999–1003. 6

Scherer, Frederic M, "Demand-pull and technological invention: Schmookler revisited," *Journal of Industrial Economics*, 1982, *34* (2), 225–237. 5

Schmookler, Jacob, *Invention and Economic Growth*, Harvard University Press, 1966. 2, 5