A Unified Theory of Structural Change*

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November 2010

Abstract

This paper uses dynamic general equilibrium and computational methods, inspired by the multi-sector growth model structure in Stephen Turnovsky's previous and more recent work, to develop a theory that unifies two of the traditional explanations of structural change: sector-biased technical change and non-homothetic preferences. More specifically, we build a multisector overlapping-generations growth model with endogenous technical-change *and* non-homothetic preferences based on an expanding-variety setup with two different R&D technologies; one for agriculture, and another for non-agriculture. Results give additional support to the biased technical-change hypothesis as an important determinant of the structural transformation. The paper also explores where this bias might come from. Our findings suggest that production-side specific factors, such as asymmetries in cross-sector knowledge spillovers could be behind it, and therefore be important to fully explain the process of structural change.

JEL Classification: O13, O14, O41.
Key words: multi-sector growth model, structural change, agriculture and non-agriculture R&D, directed innovation, hon-homothetic preferences.

*We thank Santanu Chatterjee, Walt Fisher, Gerhard Sorger, Steven Turnovsky, and participants in the Workshop in Honor of Stephen J. Turnovsky May 2010, and the Society of Computational Economics session at the 2010 ASSA meeting in Atlanta for valuable comments. Financial support from Ministerio de Ciencia e Innovación and FEDER funds under project SEJ-2007-62656, and from Instituto Valenciano de Investigaciones Económicas is gratefully acknowledged. The views expressed in this study are the sole responsibility of the authors and should not be attributed to the International Monetary Fund, its Executive Board, or its management.

1 Introduction

Stephen Turnovsky's graduate textbook *Methods of Macroeconomic Dynamics* made a powerful mark on the field of macroeconomics by providing crucial building blocks and useful applications of general equilibrium intertemporal dynamic macroeconomic models. A notable offspring of such dynamics methods is a class of models employing multi-sectoral dynamics in a long-run growth context, also developed by Turnovsky (and coauthors; including, among may others, Fisher and Turnovsky, 1998; Eicher and Turnovsky 1999a,b, 2001; Alvarez-Cuadrado, Monteiro and Turnovsky, 2004; and Turnovsky, 2004), which has been the cornerstone of an entire research agenda which to this date is vibrant and keeps branching out to new applications of macroeconomics.

This paper uses dynamic general equilibrium and computational methods that we first discovered as junior assistant professors studying Turnovsky's book and extends our earlier work (Papageorgiou and Perez-Sebastian, 2004; 2006; 2007) inspired by the multi-sector growth model structure in Turnovsky's previous and more recent work. More specifically, the goal of this paper is to construct a model that can unify two of the traditional explanations of the structural transformation; namely sector-biased technical change pioneered by Ngai and Pissarides (2007), and non-homothetic preferences pioneered by Konsamut *et al.* (2001). The importance of integrating both approaches is defended and left to future research by, for example, Acemoglu (2008).

A well-documented feature of modern growth commonly called *structural change* or *structural transformation* is the decline of agriculture and the rise of services.[1] Structural transformation has been studied extensively, resulting in two prominent albeit divergent theories.[2] The first one is based on consumer non-homothetic preferences pioneered by Konsamut, Rebelo and Xie (2001). The second builds on sector-biased technical change and is represented by the influential contributions of Baumol (1967) and Ngai and Pissarides (2007).

[1] This reallocation process has been documented by early pioneer contributions including Clark (1940), Kuznets (1957), and Chenery (1960).

[2] See e.g., Kuznets (1966) and Baumol (1967), Echevarria (1997), Parente *et al.* (2000), Caselli and Coleman (2001), and Strulik and Weisdorf (2008).

Konsamut, Rebelo and Xie (2001) were the first to present a model consistent with both the Kaldor facts of constant growth rate, capital-output ratio, real rate of return to capital, and input shares in national income, and the dynamics of sectoral labor reallocation. These authors pioneered a model in which balanced growth is consistent with structural change. These authors assumed a preference specification consistent with the income elasticity of demand less than one for agricultural goods, equal to one for manufacturing goods, and greater than one for services. Their additional assumption of non-homothetic preferences was sufficient, for on otherwise standard neoclassical model, to allow for structural change.

An alternative theory of structural change is based on the technological hypothesis, proposed by Baumol (1967) and formalized by Ngai and Pissarides (2007) who develop a formal framework that builds on the response of hours of work to the uneven distribution of technological change across production sectors. They show that if there are two sectors, one of them characterized by a larger total factor productivity (TFP) growth, hours of work rises in the stagnant sector if the two goods have a relatively large degree of complementarity; labor moves in the direction of the progressive sector otherwise.

An important conclusion from the above literature is that biased technical change has more weight on the explanation of the structural transformation than non-homothetic preferences (see Ngai and Pissarides 2007, and Buera and Kaboski 2009).[3] In this paper, we examine whether a more general approach with endogenous innovation can encompass both of these influential theories of structural transformation, and whether the conclusion holds in it.

In particular, we first ask whether the sector-biased technical change hypothesis can follow from the non-homothetic preferences hypothesis. We examine the idea that freeing labor from agriculture to feed other economic sectors might require a larger total factor productivity (TFP) growth in agriculture; and that, as a consequence, biased TFP growth could be an endogenous response to the non-homotheticity of the

[3] Iscan (2010) presents quantitative results that suggest that non-homothetic preferences had a larger weight in the structural transformation in the early stages of the process, but that in the last 70 years the main engine has been the technological biased. In Iscan's model, technical change is exogenous.

utility function. Second, the paper searches for features of technological change that can be responsible for the observed evolution of sectoral TFP.

In order to accomplish these goals, we build a multisector overlapping-generations model of endogenous technical-change and economic growth. The production side of the economy feeds from Romer (1990) and Jones (1995). The setup shows expanding-varieties of intermediate goods that are designed using sector-specific R&D technologies. Production is disaggregated into two activities: agriculture, and non-agriculture. Preferences are non-homothetic. We formalize the notion that inventors decide the kind of technological improvements that they create. The paper is then also related to the literature on directed technical change such as Acemoglu (2002, 2003). But unlike these papers, we focus on ideas directed to different sectors instead of different inputs.

A setup in which R&D technologies are symmetric across sectors is first considered. Results imply that the sector-biased technical change hypothesis can not follow from non-homothetic preferences only, because the latter hypothesis generates both larger TFP growth and labor inflows in the same sector, irrespective of the elasticity of substitution between final goods. To generate reasonable dynamics, the long-run value of TFP in agriculture needs to be larger than in other sectors. This is prevented in our base model by the lower weight of agricultural-goods consumption in the utility function. We then modify the R&D technologies to consider that agriculture benefits from cross-sector knowledge spillovers. The resulting model predictions are now able to reproduce the main patterns of TFP growth observed in the data.

The rest of the paper is organized as follows. Section 2 introduces the basic model. Its predictions are analyzed in section 3. Section 4 presents results in the case where the R&D technologies allow for cross-sector knowledge spillovers. Section 5 concludes.

2 The Model

2.1 Households

We consider an economy composed of overlapping generations of individuals. The size of generation t is L_t, and grows exogenously at rate n. Individuals have preferences over consumption of agricultural and non-agricultural goods. They are endowed with one unit of labor when young that is inelastically supplied to the production activities.

For simplicity, we assume that consumption only occurs in the second period of life, thus abstracting from consumption/saving decisions.[4] At time t, a representative consumer is solving the following problem:

$$\max \left\{ v(c_{at+1}, c_{nt+1}) = \left[\sum_{i=a,n,} \gamma_i (c_{it+1} - \bar{c}_i)^{(\varepsilon-1)/\varepsilon} \right]^{\varepsilon/(\varepsilon-1)} \right\},$$

subject to

$$P_{at+1} c_{at+1} + c_{nt+1} = (1 + r_{t+1})\, w_t;$$

where $\varepsilon \in (0, \infty)$; c_{at} and c_{nt} are consumption at date t of the agricultural and non-agricultural products, respectively;[5] r and w are the rental rates of capital and labor; P_{at} is the price of agricultural goods; $\gamma_a + \gamma_n = 1$; finally, $\bar{c}_i$ represents a minimum subsistence-consumption level if positive, or a minimum endowment level if negative. All prices in the model are expressed in units of the non-agricultural goods. The right-hand side of the budget constrain reflects equality between interest rate and the return to capital.

The first-order conditions to this problem provide the optimal weights in the consumption bundle as follows:

$$\left(\frac{P_{at}}{\gamma_a} \right)^{\varepsilon} (c_{at} - \bar{c}_a) = \left(\frac{1}{\gamma_n} \right)^{\varepsilon} (c_{nt} - \bar{c}_n).$$

[4] This should not have any impact on our results because saving only affects the total amount of capital, whereas our findings are driven by differences in the allocation of resources between the two sectors. Capital is not an important determinant of these differences given our assumption that the elasticity of capital is the same in the agriculture and non-agriculture production functions.

[5] Having three sectors such as agriculture, manufacturing, and services, instead of two, would complicate matters without adding a significant change to the basic message of the paper.

A larger weight in the utility function or a lower price contribute to increase demand for that good.

2.2 Final-good production

A large number of firms produce goods using labor and capital, while each firm produces output Y_{it} only in one sector i, with $i \in \{a, n\}$. At date t, capital employed is composed of a mass A_{it} of differentiated producer durables. The production technology is given by:

$$Y_{it} = L_{it}^{1-\alpha} \int_0^{A_{it}} [x_{it}(z)]^{\alpha} \, dz; \tag{1}$$

where $x_{it}(z)$ and L_{it} are the amounts of equipment type z and labor employed by sector i in period t.

Firms choose the amount of each type of capital good that they want to buy, and the amount of labor that they want to hire so as to maximize profits. They solve the following problem:

$$\max_{\{x_{it}(z), L_{it}\}} \left\{ P_{it} L_{it}^{1-\alpha} \int_0^{A_{it}} [x_{it}(z)]^{\alpha} \, dz - \int_0^{A_{it}} p_{it}(z) x_{it}(z) \ dz - w_t \ L_{it} \right\};$$

where $p_{it}(z)$ is the price of durable good type z specific to sector i.

Solving this problem obtains the inverse demand functions:

$$x_{it}(z) = \left(\frac{\alpha P_{it}}{p_{it}(z)} \right)^{1/(1-\alpha)} L_{it}, \tag{2}$$

$$L_{it} = (1-\alpha) \frac{P_{it} Y_{it}}{w_t}. \tag{3}$$

2.3 Intermediate-goods production

Technology (1) employs different types of capital goods. The manufacturing process of these goods requires investing raw capital coming from saved manufacturing output. We adopt the simplest technology to manufacture capital products: one unit of capital can be converted at no cost into one unit of any variety of intermediate goods. Firms that produce the varieties hold exclusive property rights on the designs, which allows them to practice monopoly pricing. We assume that these property rights expire in one generation.[6] Capital also depreciates fully after *one* generation.

The problem of a firm that produces variety j for sector i is:

$$\max_{x_{it}(j)} \left[p_{it}(j) - (1 + r_t)\right] x_{it}(j);$$

where $p_{it}(j)$ is given by the inverse demand function of intermediate good $x_{it}(j)$, that is, by equation (2). The monopolist charges a markup η equal to the inverse of the elasticity of substitution between intermediate goods in final output production. More specifically, the optimal decision, standard in the literature, is given by:

$$p_{it}(j) = \eta_i(1 + r_t) = p_{it}, \text{ with } \eta_i = \frac{1}{\alpha} = \eta, \quad \forall j. \tag{4}$$

Since the price is the same for all varieties of intermediate goods, and they enter symmetrically in final-good production, the amount demanded for each of them will also be the same, $x_i(j) = x_i \ \forall j$. Profits then equal:

$$\pi_{it}(j) = (\eta - 1)(1 + r_t)x_{it} = \pi_{it}, \text{ also } \forall j; \tag{5}$$

2.4 R&D sector

Under the assumption of free entry into the *R&D* activity, there is a continuum of firms that invest in deliberate *R&D* effort directed to create sector-specific varieties of intermediate goods. These firms rent labor supplied by young individuals at the beginning of period t. Researchers benefit from the existing knowledge base A_{it} to prospect for new designs. The total number of ideas specific to sector i, with $i = \{a, n\}$, that the R&D activity delivers by the end of the period is given by

$$A_{it+1} = \mu A_{it}^{\phi} L_{A_{it}}^{\lambda-1} L_{A_{it}}; \tag{6}$$

where $L_{A_{it}}$ is the number of workers employed in *R&D* directed to sector i.

There are several features of this *R&D* specification that are worth emphasizing. First, the LHS is not written in increments, as most of the literature does, but in levels. This is, however, consistent with the idea that technological levels can not

[6] If one generation is 30 years. This implies a depreciation rate of ideas of about 10%, figure consistent with the evidence provided by Caballero and Jaffe (1993).

decrease. The reason is that, even though innovations can not depreciate, they can become obsolete. This is what occurs every single period in our model. In particular, as in Jones and Williams (2000), we assume that new generations of inventions come in packages. A package is composed of both upgrades of old capital designs and completely new ones. The key is that the whole new vintage or package of ideas (A_{it+1}) has to be adopted together, which displaces the old one (A_{it}).

Under the above assumption, expression (6) is correct as long as $A_{it+1} \geq A_{it}$. This always true in our simulations. In addition, the adoption of the new package, besides bringing technological upgrades, needs to be profitable – notice that producers could continue using old designs purchased in perfectly competitive markets because patents last for one period. The appendix shows that the new vintage will be adopted if and only if the markup η_i charged by monopolists is below $(A_{it}/A_{it-1})^{(1-\alpha)/\alpha}$. For the shake of simplicity, we do not impose this condition. However, as will become clear later, this should not have any effect on the main results of the paper. The reason being that the markup and the rate of technical change reinforce each other in the same direction when the condition is binding. As a result, the main consequence of a markup that followed TFP growth would be an amplification of the cross-sector differences in TFP growth.

Second, returns to labor at the individual and aggregate levels differ. On the one hand, investment displays constant returns at the individual level. On the other, the term $L_{A_{it}}^{\lambda-1}$ implies that researchers generate negative externalities to each other. This can be a consequence of patent races for example. The result is that the R&D technology at the aggregate level shows diminishing returns ($0 < \lambda < 1$) to R&D effort. More specifically, in the symmetric equilibrium in which firms end up, expression (6) becomes:

$$A_{it+1} = \mu A_{it}^{\phi} L_{A_{it}}^{\lambda}.$$

Finally, the *R&D* specification allows for intertemporal knowledge spillovers ($0 < \phi < 1$).

After coming up with new innovations, inventors obtain patents that are immediately sold.[7] Those that purchase them invest capital at the end of date t to build producer-durable units that will be available for final-goods manufacturing at $t+1$ at monopoly prices. The outcome of this entire process is that the firm that sells the intermediate goods obtains an amount of profits equal to π_{it}, given by expression (5).

The solution to the R&D allocation problem is characterized by the next two conditions:

$$Q_{it}A_{it+1} = w_t L_{A_{it}}, \tag{7}$$

$$Q_{it} = \frac{\pi_{it+1}}{1+r_{t+1}} = (\eta - 1)\, x_{it+1}. \tag{8}$$

Free entry implies that total revenues from the sale of designs at the end of the period must equal the cost of R&D. Calling Q_{it} the price of the patent, we then get the non-arbitrage condition given by expression (7). Intermediate-goods producers will buy the patent and produce under monopolistic competition next period if the price of the patent does not exceed the present value of expected profits. But in equilibrium they must be indifferent between producing and not, so condition (8) must also hold.

2.5 Market clearing and aggregate outcomes

The agricultural sector produces output that is used for final consumption, while the non-agricultural sector generates output that can be used for final consumption and saved as capital. Hence, market clearing in goods markets requires:

$$Y_{at} = L_{t-1}c_{at}, \tag{9}$$

and

$$Y_{nt} = L_{t-1}c_{nt} + I_t; \tag{10}$$

where I_t is gross investment in capital at time t.

Let us now focus on input markets. Labor is supplied inelastically by consumers, therefore in equilibrium

$$L_t = \sum_{i=a,n} L_{it} + \sum_{i=a,n} L_{A_{it}}. \tag{11}$$

[7] We assume that there exist institutions that guarantee such a thing.

Saving in our model economy is entirely due to salary income, and is employed to construct physical capital and finance the purchase of patents:

$$w_t L_t = K_{t+1} + \sum_{i=a,n} Q_{it} A_{it+1}. \tag{12}$$

In the last equality, K_t represents the aggregate capital stock in the economy at time t. Since producer durables fully depreciate upon use, it follows that:

$$I_{t-1} = \sum_{i=a,n} \left[\int_0^{A_{it}} x_{it}(z)\ dz \right] = \sum_{i=a,n} A_{it} x_{it} = K_t. \tag{13}$$

In turn, the capital stock in sector i can be written as $K_{it} = \int_0^{A_{it}} x_{it}(z)\ dz = A_{it} x_{it}$. Furthermore, given that prices and use of intermediate goods are the same within both sectors, we can rewrite equation (1) at the aggregate level as:

$$Y_{it} = \left(A_{it} L_{it}\right)^{1-\alpha} K_{it}^{\alpha} = L_{it}\ A_{it}^{1-\alpha} k_{it}^{\alpha}; \tag{14}$$

where k_{it} gives the capital labor ratio K_{it}/L_{it} in sector i at date t.

This expression, and optimality conditions (2)-(4) imply that:

$$1 + r_t = \frac{\alpha}{\eta} P_{it} A_{it}^{1-\alpha} k_{it}^{\alpha-1}, \tag{15}$$

$$w_t = (1-\alpha) P_{it} A_{it}^{1-\alpha} k_{it}^{\alpha}. \tag{16}$$

Then

$$k_{at} = k_{nt},$$

and

$$P_{at} = \left(\frac{A_{nt}}{A_{at}}\right)^{1-\alpha}.$$

Defining $k_t = K_t/L_t$, it follows from (13) that:

$$\left(l_{at} + l_{nt}\right) k_{it} = k_t. \tag{17}$$

From (7), (8) and (12), we get:

$$k_{t+1}\left(1+n\right)\left(\eta - 1\right) = w_t \left(l_{A_{at}} + l_{A_{nt}}\right), \tag{18}$$

In turn, equations (7), (8), (11), (12) and (18) deliver $k_{it} = \eta k_t$. An implication of all the above is that the ratio of the output shares equals the ratio of the labor shares:

$$\frac{P_{at} y_{at} l_{at}}{y_{nt} l_{nt}} = \frac{l_{at}}{l_{nt}}. \tag{19}$$

2.6 The equation system

The following equations, along with (15) and (16), provide the system that characterizes dynamics in this economy as a function of prices and predetermined stocks:

$$\left(\frac{P_{at}}{\gamma_a}\right)^{\varepsilon}(c_{at} - \bar{c}_a) = \left(\frac{1}{\gamma_n}\right)^{\varepsilon}(c_{nt} - \bar{c}_n),$$

$$A_{it+1} = \mu A_{it}^{\phi}\left[l_{A_{it}} L_t\right]^{\lambda},$$

$$k_{t+1}(1+n) + w_t\left(l_{A_{at}} + l_{A_{nt}}\right) = w_t,$$

$$P_{at+1} c_{at+1} + c_{nt+1} = (1 + r_{t+1}) w_t,$$

$$y_{at} l_{at} = \frac{c_{at}}{1+n},$$

$$y_{nt} l_{nt} = \frac{c_{nt}}{1+n} + k_{t+1}(1+n),$$

$$y_{it} = A_{it}^{1-\alpha} k_t^{\alpha} l_{it},$$

$$l_{at} + l_{nt} + l_{A_{at}} + l_{A_{nt}} = 1,$$

$$\frac{l_{at+1}}{l_{nt+1}} \frac{l_{A_{nt}}}{l_{A_{at}}} = 1,$$

$$\frac{k_{nt}}{k_t} = \eta;$$

where l_{it} and $l_{A_{it}}$ are the fractions of the labor force in the final goods and $R\&D$ of sector i at date t, respectively.

The above system simplifies to:

$$A_{it+1} = \mu A_{it}^{\phi}\left[l_{A_{nt}} L_t\right]^{\lambda}, \tag{20}$$

$$P_{at} = \left(\frac{A_{nt}}{A_{at}}\right)^{1-\alpha}, \tag{21}$$

$$(c_{nt} - \bar{c}_n) \sum_{i=a,n} P_{it}^{1-\varepsilon}\left(\frac{\gamma_i}{\gamma_n}\right)^{\varepsilon} + \sum_{i=a,n} P_{it}\ \bar{c}_i = \alpha^2 A_{nt}^{1-\alpha}(\eta k_t)^{\alpha}(1+n), \tag{22}$$

$$k_{t+1} = \frac{\alpha (1-\alpha) w_t}{(1+n)}, \tag{23}$$

$$l_{at} = \frac{P_{at}^{-\varepsilon} \left(\frac{\gamma_a}{\gamma_n}\right)^{\varepsilon} \left[\alpha^2 A_{nt}^{1-\alpha} (k_t/\alpha)^{\alpha} (1+n) - \bar{c}_n\right] + \bar{c}_a}{\left[1 + P_{at}^{1-\varepsilon} \left(\frac{\gamma_a}{\gamma_n}\right)^{\varepsilon}\right] A_{at}^{1-\alpha} (k_t/\alpha)^{\alpha} (1+n)}, \tag{24}$$

$$l_{nt} = \alpha - l_{at}, \tag{25}$$

$$l_{A_{at}} = \left(\frac{1}{\alpha} - 1\right) l_{at+1}, \tag{26}$$

$$l_{A_{nt}} = (1-\alpha) - l_{A_{at}}, \tag{27}$$

$$L_t / L_{t-1} = 1 + n; \tag{28}$$

with k_t, A_{it}, L_t being predetermined.

3 Dynamics of Structural Change

The observed change in the contribution of the primary sector to GDP in the last 200 years has been impressive. The share of agriculture in US national income, for example, went down from roughly 20% in 1850 to around 0.7% in year 2000. At the same time, growth of TFP has been higher in farming than in the rest of the economy in the last 90 years. This pattern of relative TFP growth is supported by data on the relative price of agricultural goods. In particular, evidence suggests that the relative price of agricultural goods rose over the period 1880 to 1920 and declined after that.[8]

This section carries out numerical experiments to analyze the transitional dynamics of the model. Our goal is to see whether the unified theory can reproduce these stylized facts and, therefore, encompass the two traditional explanations of the structural transformation. But first, we need to give values to the different parameters, and decide on the starting point of the simulation. For this, we will employ the very long-run equilibrium towards which variables converge.

3.1 Unbalanced growth and the asymptotic steady state

Ours is an unbalanced growth model because of the non-homotheticity of preferences. As Kongsamut *et al.* (2001) show in this framework, variables only reach a constant

[8] See, for example, Caselli and Coleman (2001), Kongsamut *et al.* (2001), and Johnson (2002).

growth rate in the particular case that $\bar{c}_a(P_{at}/\gamma_a)^{\varepsilon} = \bar{c}_n(1/\gamma_n)^{\varepsilon}$. In all other scenarios, variables approach and get infinitely close to the balanced-growth path associated with the zero subsistence-consumption case.

When $\bar{c}_a = \bar{c}_m = 0$, per capita variables and wages grow at the same rate along the balanced-growth path, and this rate equals the rate of technological change. The rest of the variables, and in particular, the labor shares, the price of agricultural goods, and the interest rate remain constant.

Specifically, let G_z be the gross growth rate of variable z, and eliminate the time index to denote steady-state values. Clearing conditions (9)-(13) imply that $G_{Y_a} = G_{c_a} G_L$, $G_{Y_n} = G_{c_n} G_L = G_K$, and $G_{L_a} = G_{L_n} = G_{L_{A_a}} = G_{L_{An}} = 1 + n$. Equations (20) and (21) imply that P_{at} remains constant at steady state because $G_{A_a} = G_{A_n} = (1+n)^{\lambda/(1-\phi)}$.

Equation (14) then implies that $G_{Y_i} = G_{A_i}$. Finally, given the output aggregate $Y_t = P_{at} Y_{at} + Y_{nt}$, we obtain that

$$G_y = (1+n)^{\lambda/(1-\phi)}; \tag{29}$$

where y is per capita income.

Table 1: Benchmark parameter values

λ	0.50	γ_a	0.00004	$\bar{c}_a$	0.05	α	0.66
ϕ	0.75	n	0.01^{30}	$\bar{c}_m$	0	ε	0.5

3.2 Calibration

Table 1 shows the parameter values chosen. An intermediate value is assigned to the degree of diminishing returns to $R\&D$ effort, $\lambda = 0.5$. The very long-run gross growth rate of per capita income G_y is equalized to 1.8113; which is the consequence of growing annually at a 2 percent during one period or 30 years. The annual growth rate of the population is assumed to be 1 percent, thus implying for the same reason that $n = 0.3478$. By equation (29), all these values require that the intertemporal knowledge-spillover parameter ϕ equals 0.75.

We think of capital broadly composed of physical as well as human capital components, and therefore choose the capital share $\alpha = 0.66$. The value of the elasticity of substitution between consumption goods is taken from Buera and Kaboski (2009), $\varepsilon = 0.5$. The minimum-consumption requirement $\bar{c}_a$ is equalized to 0.05, and $\bar{c}_n$ to 0. For the weights of the two types of consumption in the utility function, we use the fact that agricultural GDP as a share of total GDP in 2002 was 0.7 percent, as compiled by the Economic Research Service the USDA using data from the Bureau of Economic Analysis. This share implies, in turn, by equations (9), (10), (19) and (23) that $\gamma_a = 0.00004$.

To choose initial values of the state variables, we assume that the economy begins from a steady state in which $c_{at} = \bar{c}_a$, $c_{mt} = 0$, $n = 0$, $G_{A_t} = 1$, and the markup that intermediate goods producers are able to charge is very small, namely $\eta = 1/0.997$.[9] This could be a consequence of a poorly developed patent-enforcement system. Equations (9) and (22) then require that $l_{a0} = \alpha/\eta$. Then, labor market clearing and expression (20) give that $P_{a0} = (1/\alpha - 1)^{\lambda(1-\alpha)/(1-\phi)}$, (23) that $k_0 = P_{a0}\bar{c}_a(1-\alpha)/[\alpha(1+n)^2]$, and equation (9) that $A_{a0} = [\bar{c}_a/(\alpha\eta^{\alpha-1}k_t^{\alpha})]^{1/(1-\alpha)}$. Finally, expression (20) provides A_{m0} and μL_0^{λ}.

3.3 Results

Figure 1 presents the adjustment paths for consumption shares (top panel), output shares (middle panel), and TFP growth (bottom panel) for the parameter values and starting coordinates described above. Because expression (19) implies that relative labor shares exactly equal relative output shares, the labor shares are not shown.

The simulation begins in a stagnant economy with a relatively large share of agriculture in GDP of 66 percent, and an even larger share of agricultural goods in total consumption of 100 percent. The shocks that provoke the transition are an exogenous increase in the population growth rate from zero to 1 percent, and the

[9] Our starting point resembles a Malthusian stage characterized by economic stagnation, zero population growth, and relatively low levels of R&D activity. The model, however, does not attempt to explain the Malthusian world; the model is one of modern growth in which R&D effort propels innovation and growth. Some features of the Malthusian economy are used as a simple way to obtain the initial coordinates.

establishment of a strong paten system that allows firms charging their preferred markup $\eta = 1/\alpha$. This is what allows the growth of TFP.

At impact TFP growth achieves its largest values, and then progressively decreases. Higher population is able to generate more ideas, and output and consumption shares start their transition towards an economy in which non-agriculture is the most important activity. The transition is monotonic and relatively fast. The one of output and consumption is almost finished after 7 generations, while that one of TFP growth is still alive after 10.

The fact that the weight of the primary sector in total GDP declines and the one of the non-agriculture rises as the economy develops is a consequence of the non-homotheticity of preferences, and reproduces a main pattern of the structural transformation. The evolution of TFP, however, is not consistent with the facts. Non-agriculture TFP growth in the model economy is always the fastest, although agriculture eventually converges to the productivity growth rates of the rest of the economy. The predicted patterns do not depend on the value of $\bar{c}_a$ nor on the value of ε. In particular, changes in $\bar{c}_a$ are fully neutral, whereas increases in the elasticity of consumption-goods substitution only cause the convergence path to be slightly smoother.

These findings suggest that non-homothetic preferences *per se* can not account for the evolution of TFP. An alternative is that factors specific to the production technology contribute to the structural transformation. Next we investigate whether differences in the intensity of cross-sector knowledge spillovers can help reconcile our theory with the facts.

4 Cross-Sector Knowledge Spillovers

Let us now consider that the agricultural sector benefits from spillovers coming from the rest of the economy, in line with evidence provided, for example, by Johnson and Evenson (1999). These authors argue that R&D spillovers are significant contributors to agricultural productivity growth and that, in particular, sectors such as chemicals, machinery, plastics, fabricated metals, and electric products contribute to it. The agricultural R&D technology now takes the form:

$$A_{at+1} = \mu A_{at}^{\phi} A_{nt}^{\beta} L_{A_{at}}^{\lambda}; \tag{30}$$

where $\beta > 0$ is the spillover parameter.

It is easy to show that the system of equations that characterize the model dynamics remains the same with the exception of the new *R&D* technology that produces ideas specific to the primary sector. In particular, the system is now composed of conditions (20) with $i = n$, (21) to (28), and (30).

A difference compared to the previous scenario is that the price is no longer approaching a constant value because it decreases with A_{at}. This feature of the model implies that, with spillovers, variables approach a balanced growth path only if $\varepsilon = 1$; but for $\varepsilon = 0.5$, no such reference exists. This lead us to maintaining the calibrated parameters as in Table 1.

To determine the size of the spillover parameter, we look at Bernard and Jones (1996, Table 1) who estimated TFP growth in the agricultural sector during the period 1970-1987 to be double that of the industrial sector. To reproduce this difference between agriculture and non-agriculture in our model after 10 periods, we assign a value $\beta = 0.214$.

The computation of the initial values for the different state variables follows the same logic as above. A steady-state equilibrium with $c_{at} = \bar{c}_a$, $c_{nt} = 0$, $n = 0$, and $\eta = 1/0.997$ still exists, although showing that needs a bit more algebra. Equations (9) and (22) again give $l_{a0} = \alpha/\eta$. In turn, combining expressions (10), (20), and (23) obtains

$$k_0 = \left\{ \left[\left(\frac{1-\alpha}{\alpha} \right)^{\frac{\lambda}{1-\phi}} \left(\frac{\bar{c}_a}{\alpha} \right)^{\frac{1}{1-\alpha}} \eta \right]^{\frac{1}{1+\beta/(1-\phi)}} \frac{(1-\alpha)^{\frac{1}{1-\alpha}}}{\eta} \right\}^{\frac{1}{1+\frac{\alpha}{1-\alpha}\frac{1}{1+\beta/(1-\phi)}}}.$$

Knowing k_0, we can easily recover A_{n0}, A_{a0}, and μL_0^{λ}.

Results for consumption shares, output shares and TFP growth are presented in the top, middle and bottom charts of Figure 2, respectively. Starting again from a relatively large share of agriculture in GDP of 66 percent, an exogenous increase in the population growth rate from zero to 1 percent, and in the markup from 1/0.997

to 1/0.66 triggers structural transformation and the transition to positive economic growth. The model shows again the highest TFP growth rates at impact, monotonically decreasing after that point. As technology starts improving, the weight of farming in total GDP declines, while the weight of non-agriculture rises. However unlike in the case without spillovers, TFP growth in agriculture is below that for non-agriculture only temporarily. After some periods, technological change in farming becomes the fastest. These trends are consistent with the main patterns observed in the data.

Regarding comparative dynamics (not shown but available upon request), the elasticity of substitution has an impact although relatively small. As ε rises, convergence becomes a bit slower, and long-run differences in TFP growth between the two sectors become larger. Subsistence consumption requirements, on the other hand, have a significant effect when spillovers are present. In particular, the transition becomes faster as $\bar{c}_a$ rises, and differences in TFP growth between the activities get larger.

5 Conclusion

Stephen Turnovsky's work on multi-sector growth models has inspired a vibrant literature that is growing strong to this day. This paper extends this line of research by using dynamic general equilibrium and computational methods, in an attempt to develop a theory that unifies two of the traditional explanations of structural change: sector-biased technical change, and non-homothetic preferences. More specifically, we build a multisector overlapping-generations growth model that incorporates both endogenous technical-change and non-homothetic preferences. Following a minimalist approach, the model is based on an expanding-variety setup with only two types of R&D technologies; one for agriculture, and the other for non-agriculture.

We first ask whether homothetic preferences can be the cause of the observed evolution of sectoral TFP that represents the basic element of the sector-biased technical change hypothesis. The analysis shows that this is not possible. Our baseline model, in which cross-sector differences come from only consumer preferences, predicts that agriculture is the most stagnant activity, a prediction not consistent with evidence.

We then ask a follow-up question: What kind of differences between sectors can be responsible for TFP growth? When we consider knowledge spillovers from the rest of the economy into agricultural R&D, the model is able to reproduce evolution of consumption shares, output shares, and TFP growth in agriculture and in non-agriculture consistent with evidence. We therefore conclude that production-side specific factors, such as asymmetries in cross-sector knowledge spillovers, are needed to reconcile the model with the main patterns observed in the data.

Although directed technical change can reconcile the two traditional theories of structural transformation, our findings depart from the sector-biased technical change hypothesis in one crucial way. The evolution of TFP does not need to be linked to a relatively low elasticity of consumption-goods substitution to be consistent with structural transformation. Endogenous technical change allows the agricultural sector to shift from being the most stagnant to being the most vibrant sector, therefore freeing labor to the rest of the economy, irrespective of the value of the elasticity of substitution.

It is also interesting to note that our finding highlighting the need for cross-sector variability and knowledge spillover effects is the main research topic in a related literature that tries to explain cross-country growth variation by examining sectoral resource (mis)allocations and their effects on aggregate TFP (see e.g. Restuccia and Rogerson, 2008, and Hsieh and Klenow, 2009).

We conclude with a cautionary remark. Our analysis provides the simplest possible disaggregated setup to consider a unified theory of structural transformation. More complicated multisector models are likely to be more successful in matching the data. For example, we believe that further work could look at even more disaggregated setups, and search for sectoral asymmetries in manufacturing and services. Recent emphasis on producing more and better quality data at the sectoral level should provide further incentives to extend the analysis in this paper further.

A Restricted markup

All available designs become displaced by updates after one period. A final good producer at t can purchase the varieties A_{it-1} at the marginal cost price or buy the new cluster A_{it} of intermediate goods at markup price. The profits of a producer of final goods in each case are, respectively,

$$\Pi_{it}^{old} = x_{it}^{old}\left[(1+r_t)\,A_{it-1}\left(\frac{1}{\alpha}-1\right) - w_t\left(\frac{(1+r_t)}{\alpha P_{it}}\right)^{\frac{1}{1-\alpha}}\right],$$

$$\Pi_{it}^{new} = x_{it}^{new}\left[\eta_{it}\,(1+r_t)\,A_{it}\left(\frac{1}{\alpha}-1\right) - w_t\left(\frac{\eta_{it}\,(1+r_t)}{\alpha P_{it}}\right)^{\frac{1}{1-\alpha}}\right].$$

It follows that the final good producer will adopt the new technology if and only if

$$\eta_{it} \leq \left(\frac{A_{it}}{A_{it-1}}\right)^{\frac{1-\alpha}{\alpha}}.$$

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Figure 1: Dynamic paths for consumption shares (top), output shares (middle) and TFP growth (bottom)

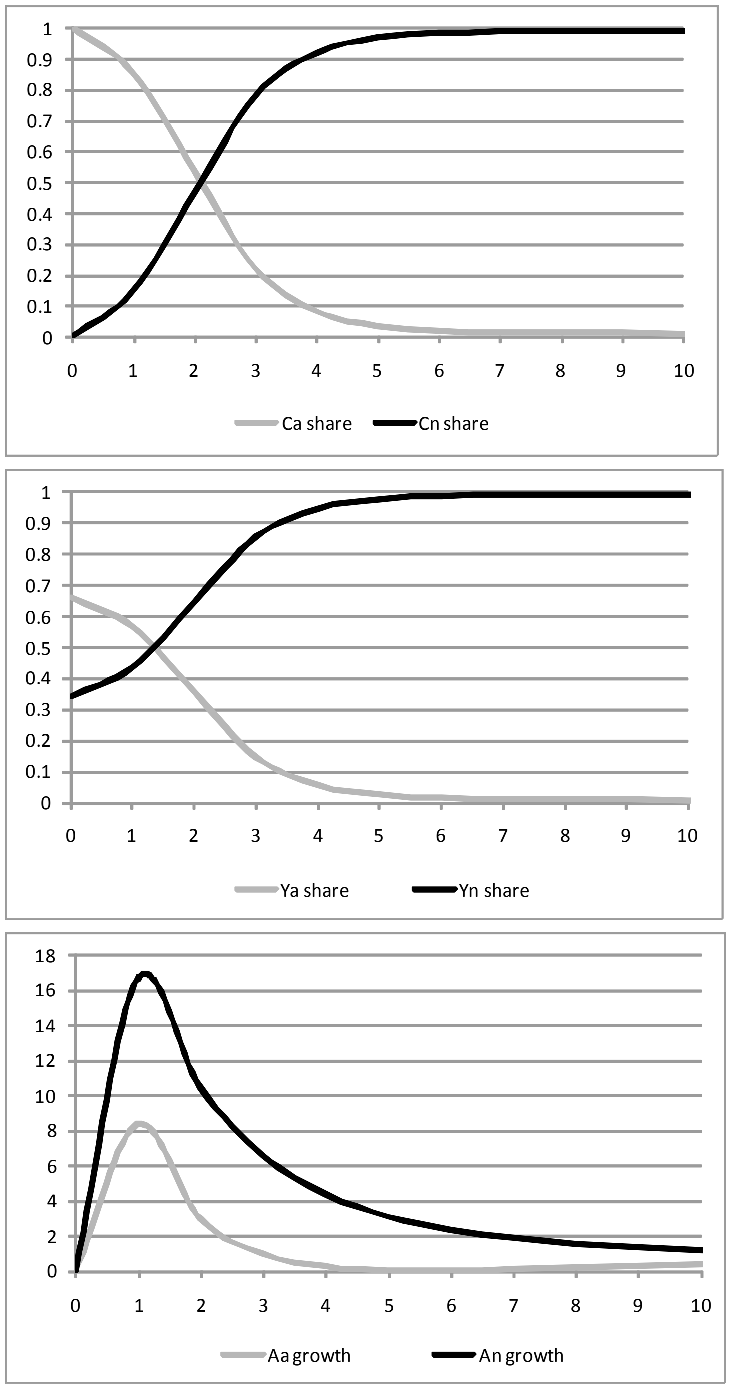

Figure 2: Dynamic paths for consumption shares (top), output shares (middle) and TFP growth (bottom), case with spillovers