Development Priorities:
The Relative Benefits of Agricultural Growth

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ABSTRACT

Should agriculture or non-agriculture be a priority for development? We revisit this question using a two-sector, three-factor dynamic model with an asymptotic balanced growth path. The model allows a forward-looking assessment of development priorities based on lifetime welfare. A comparison of sector-specific productivity gains indicates that gains in non-agriculture are often more valuable, even when agriculture is initially the largest sector in terms of employment. We discuss the robustness of this result, and how international capital mobility, capital intensity, demographics, the discount rate, and taxes on profits influence investment and structural transformation.

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1 Introduction

Should developing country governments and aid donors make agriculture their first priority, or manufacturing and services? There are many possible considerations, their relative importance is unknown, and the context could matter in ways that are hard to establish. For reasons like these, it seems likely that researchers will never arrive at definitive answers, and textbooks on development refrain from drawing firm conclusions. Yet, in practical terms, the question is one that cannot be avoided: an answer of some form will be implicit, at least, in a range of development policies and decisions.

The question is difficult for a number of reasons, beyond the sheer range of considerations. First, the overall effect of sector-specific development policies is inherently a general equilibrium question. Second, because the effects of policies vary over time, it is also a dynamic question. Third, although a traditional framing of development policies would examine their effects on the growth rate, that approach is incomplete. Different scenarios will often be associated with different paths for the capital stock. In turn, the scenarios will differ in how much consumption is foregone along the equilibrium path. This suggests that analysis of effects on growth should be supplemented by a welfare analysis, based on the lifetime trajectories of households.

With these points in mind, this paper uses a dynamic general equilibrium approach to study effects on lifetime welfare, for model economies loosely based on low-income countries in sub-Saharan Africa. The aim is not to make forecasts, but to illustrate paths that might be open to African economies undergoing structural transformation, and how those paths would be affected by shifts in sector-specific productivity levels. To do this, we adopt a two-sector, three-factor growth model with an asymptotic balanced growth path and endogenous saving. At each instant, households have Stone-Geary preferences over the two goods. The saving decision is otherwise specified as in the conventional Ramsey model. Structural transformation is influenced partly by exogenous technical progress in the two sectors, partly by capital accumulation, and (as in Ying 2014) partly by the interaction between a growing population and a fixed stock of land.

If productivity growth in the non-agricultural sector is sufficiently fast, the model yields an asymptotic balanced growth path. The employment share of the agricultural sector approaches zero asymptotically, so that the two-sector structure ultimately gives way to the one-sector Ramsey model. An advantage of the model is that we can obtain a structural transformation and (asymptotic) balanced growth without assuming knife-edge restrictions on parameters or symmetric production technologies. We introduce a computational device that helps to solve the model numerically without linearization or other approximations, even though the balanced growth path is approached only asymptotically.

Using the model, we ask whether a gradual change in the level of agricultural total factor productivity (TFP) is more or less beneficial, in welfare terms, than a similar gradual change in non-agricultural productivity. We could think of these TFP changes as reflecting, say, sector-specific investments in rural or urban infrastructure. The approach is stylized and reduced-form, but it helps to isolate some of the relevant trade-offs. In our simulations, we consider economies in which the agricultural sector is initially the largest in terms of employment. Other things equal, this suggests agricultural productivity increases will be especially beneficial. The obvious direct effect of higher TFP on output will be reinforced by dynamic effects, because higher productivity in either sector makes available extra resources for investment.

This is not the whole story, however. First, if a developing economy is experiencing a conventional structural transformation, the non-agricultural sector will be expanding over time. As it expands, the direct benefits of a productivity improvement in that sector will mount. Second, in a small open economy setting, the assumption that agriculture is less capital intensive has implications for capital accumulation. A productivity gain in agriculture causes that sector to expand, but since it is less capital intensive than non-agriculture, the aggregate demand for capital may fall. In a model with endogenous saving, this restrains capital accumulation. If instead the capital-intensive sector is made the priority for productivity gains, this leads to transitional dynamics with faster capital accumulation and faster growth in wages and capital income.

In the model we consider, it is the overall balance of these effects which influences whether agricultural or non-agricultural productivity improvement is most beneficial for lifetime welfare. The conclusion will be influenced partly by the discount rate and partly by the speed of structural transformation. One of our findings is that a forward-looking assessment may be enough to tip the balance towards non-agriculture in setting priorities, even when agriculture is initially the largest sector in terms of employment. The result is not reversed even if we reduce the rates of sector-specific technical progress, to slow down structural transformation.

But the balance can be tipped by other ways of slowing down structural transformation. One route is to assume a higher discount rate, so that households are more impatient. This matters for two reasons. First, it gives more weight in the welfare calculation to near-term outcomes, and the near term is when the agricultural sector is largest. Second, with a higher discount rate, households save less. This lowers investment, slows down the rate of structural transformation, and lowers the relative benefits of non-agricultural productivity improvement.

A second route is to assume that profits are taxed, either by the formal tax system, or perhaps through corruption and other institutional limitations, such as a risk of expropriation. This change again slows down capital accumulation and the rate of structural transformation, helping to tip the balance back towards the agricultural sector as a priority. When this effect is large, the rate of structural transformation is in the empirically relevant range, but the model implies gross investment rates that are lower than we see in the data.

To avoid misinterpretation, we acknowledge that these findings cannot resolve the larger debate. Many considerations are omitted from the analysis, such as rural off-farm employment (Foster and Rosenzweig 2008), human capital (Wingender 2015), public capital (Felice 2016), and the potential role of agricultural productivity growth in creating a domestic market for non-agricultural goods. Nor do we give any consideration to the costs and feasibility of achieving productivity improvements in a given sector, which would be needed for a full policy analysis (Dercon and Gollin, 2014). Our contribution is more limited, namely to clarify trade-offs and general equilibrium mechanisms that can help to inform the wider debate. Among these, we emphasize the role of the speed of structural transformation when forward-looking conclusions are drawn about development priorities.

The paper has the following structure. The next section provides some background discussion and context. Section 3 investigates the rate of structural transformation in eleven sub-Saharan African economies, using the new data of de Vries et al. (2015). Section 4 introduces the model and section 5 presents some variations, including partial international capital mobility. Section 6 sets out the assumptions used in the simulations, and section 7 presents the first simulation results, including a range of experiments with structural parameters. Section 8 looks at simulations with capital mobility, before section 9 concludes.

2 Background

Discussion of the relative importance of agriculture and non-agriculture has a long history in development economics. The debate emerged in the 1950s, partly through the work of Arthur Lewis, the 1979 Nobel laureate in economics. Lewis is often seen as a believer in rapid industrialization driven by investment in manufacturing, aided by government planning. But his biographers emphasize that his views were more complicated, as reflected when he advised the Gold Coast (present-day Ghana) in the early 1950s. In his 1953 report on its industrialization, he wrote that 'The most certain way to promote industrialisation in the Gold Coast is to lay the foundation it requires by taking vigorous measures to raise food production per person engaged in agriculture... To the extent to which industrialization is financed from domestic savings, it is, in the ultimate analysis, the farmers who provide the wherewithal' (Lewis 1953, quoted in Mosley and Ingham, pp. 149-150). In line with this, he recommended spending on agricultural research and rural extension services.

Was this good advice? More than sixty years later, the question remains unresolved. Contrary to Lewis, the analysis below will suggest that, as the introduction discussed, agricultural productivity gains in an open economy do not always accelerate capital accumulation.[1] This result emerges via the assumption of endogenous saving. The effect of increased agricultural productivity on saving is limited because, if households could see benefits from additional saving, they would have been saving more in any case.

This leaves the question to be determined largely by the direct benefits of productivity improvement. Here, we show that the rate of structural transformation plays a critical role. As noted earlier, the conventional argument is that productivity in the largest sector matters most; but this can be overturned when the structure of the economy is changing over time

[1] This indicates the usefulness of a dynamic general equilibrium approach. Dercon and Gollin (2014, p. 487) note that the debate on agriculture's role is underdeveloped, but stress the lack of attention to the costs and opportunity costs of agriculture-specific policies, which we do not consider.

and we make a forward-looking assessment.

Our assumption of a small open economy setting helps to simplify the analysis, but could be criticized. Gollin (2010, p. 3835) notes that most food in sub-Saharan Africa is produced within the country where it is consumed; see also Gollin et al. (2007). But imports are not unknown, even in the poorest countries (Mason et al. 2011). For example, in Malawi the most important staple food is maize, and about 40% of marketed maize is imported from nearby countries. Almost all wheat and rice consumed in Malawi is imported. More systematic evidence is provided by Mundlak and Larson (1992), who studied price variation in 58 countries over 1968-78. They found that variations in the world prices of agricultural commodities are the dominant component in the variation of domestic prices. Although their sample included only a few sub-Saharan African countries, openness is likely to have increased since the time period of their analysis. For structural transformation, the question of whether closed or open economy models are likely to be the best approximation can be considered unresolved.[2]

A secondary aim of this paper is to show that an open economy model generates more realistic paths for key variables than closed one-sector models. The transitional dynamics of the one-sector Ramsey model with isoelastic utility are known to differ from observed growth experiences. In the early stages of a transition, the Ramsey model generates a sharp decline in the return to capital, together with very high initial productivity growth, neither of which seem to be observed in the data.[3]

Several authors, including Robertson (1999), have suggested that a two-sector economy can remedy these problems, especially when that economy is open to trade. Our own two-sector, three-factor structure does much to render the solution paths more plausible. We can do this relatively simply, because we consider a small open economy in which both goods are traded.[4] In this case, goods prices are exogenous (they are set by world markets) which simplifies the analysis. Intratemporal preferences over goods still matter, but only in influencing the intertemporal decision on how much to save.

We adopt Stone-Geary preferences, in which the elasticity of intertemporal substitution is low when expenditure is low. In the one-sector case, Stone-Geary preferences are well known to generate more realistic growth paths. Under these preferences, investment may be deferred, and hence Christiano (1989) calls this the 'slow convergence model'. The large literature includes Rebelo (1992), King and Rebelo (1993), Ben-David (1998), Kraay and Raddatz (2007), Ohanian et al. (2008) and Steger (2009). Under these preferences, the elasticity of intertemporal substitution is increasing in the level of consumption.[5] This helps

[2]Much of the literature on structural transformation assumes a closed economy. This seems natural for the historical United States, but less clearly applies to present-day developing countries.

[3]King and Rebelo (1993) provide one well-known demonstration, using a version of the model calibrated to the post-war growth of Japan. The more general problems of the Ramsey model are discussed in Barro and Sala-i-Martin (2004, pp. 116-118).

[4]Work on growth in open, multi-sector economies includes Connolly and Yi (2015), Cuñat and Maffezzoli (2004), Matsuyama (1992), Święcki (2017), Uy et al. (2013) and the book by Roe et al. (2010).

[5]The wide-ranging implications of a variable intertemporal elasticity of substitution have been stressed by Bliss (2007, 2008).

to match the data, given that rates of saving and investment are often lower in poorer countries than in richer ones: see Kraay and Raddatz (2007) among others.

The literature on multi-sector models with non-homothetic preferences is extensive, but generally uses closed economy models.[6] Among previous work, the structure of our model is especially close to Roe et al. (2010). They consider dynamic general equilibrium models of small open economies with endogenous saving and Stone-Geary preferences. There are two key differences. Their approach to obtaining balanced growth differs, and they do not consider the question of development priorities, one focus of this paper.

In all our various experiments, we treat investment as endogenous and technical progress as exogenous. This choice of emphasis is broadly consistent with the findings of Baier et al. (2006) and especially Schelkle (2014). The latter uses results from development accounting to study growth and convergence outcomes, allowing efficiency growth to differ across countries. He finds that episodes of international catching up (relative to the United States) are primarily associated with rapid factor accumulation rather than changes in relative efficiency, which supports the use of models with an endogenous investment rate.

Part of the background to our paper is the perception that structural transformation has been delayed in Africa in particular, or has worked against raising aggregate productivity. McMillan et al. (2014) argue that recent changes in sectoral structure in Africa have sometimes favoured sectors with relatively low productivity at the margin. Our model assumes costless mobility of capital and labour across sectors, but could be generalized to allow for distortions. If the marginal products of labour or capital were relatively low in agriculture, as Vollrath (2009) analyses, then a TFP increase in agriculture could encourage factors to move to a sector where their productivity is lower at the margin. This would tend to reinforce our central result that, for an economy undergoing structural transformation, productivity gains in non-agriculture may be more beneficial than in agriculture.

3 Data

The rate of structural transformation will play a key role in what follows. With this in mind, we introduce a simple measure of this rate, which can be compared across countries and with later simulation results. Since our focus is primarily on low-income countries, we estimate the speed of transformation for eleven sub-Saharan African countries since the 1960s. To do this, we use the African Sector Database compiled by de Vries et al. (2015). The eleven countries in the database together account for about 70% of the region's GDP.

Figure 1 shows the path of the agricultural employment share for these eleven countries over 1961-2011. In figures 2 and 3, for greater clarity, we show the logarithm of the share in separate panels, together with linear time trends. It is clear that the eleven countries vary greatly in the rate of structural transformation. In the case of Nigeria, there has been a

[6] See, for example, Kongsamut et al. (2001), Irz and Roe (2005), Gollin et al. (2007), Alonso-Carrera and Raurich (2015), Alder et al. (2019) and the book by Bertola et al. (2006). Hayashi and Prescott (2008) consider both closed and open economy models.

major reversal in sectoral structure, and hence slow change over the period as a whole.

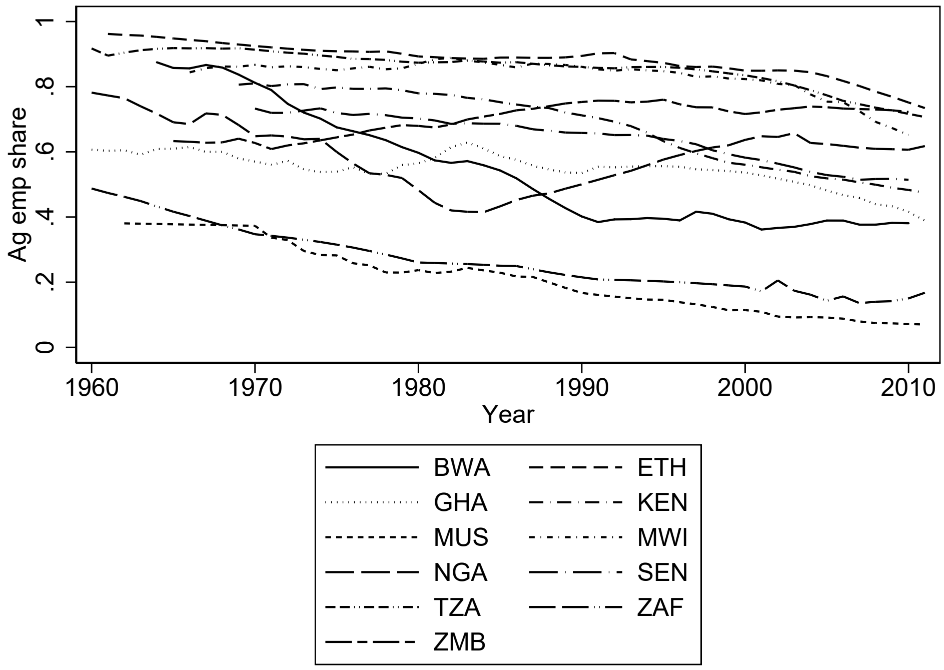

Figure 1: Agricultural employment shares for 11 SSA countries

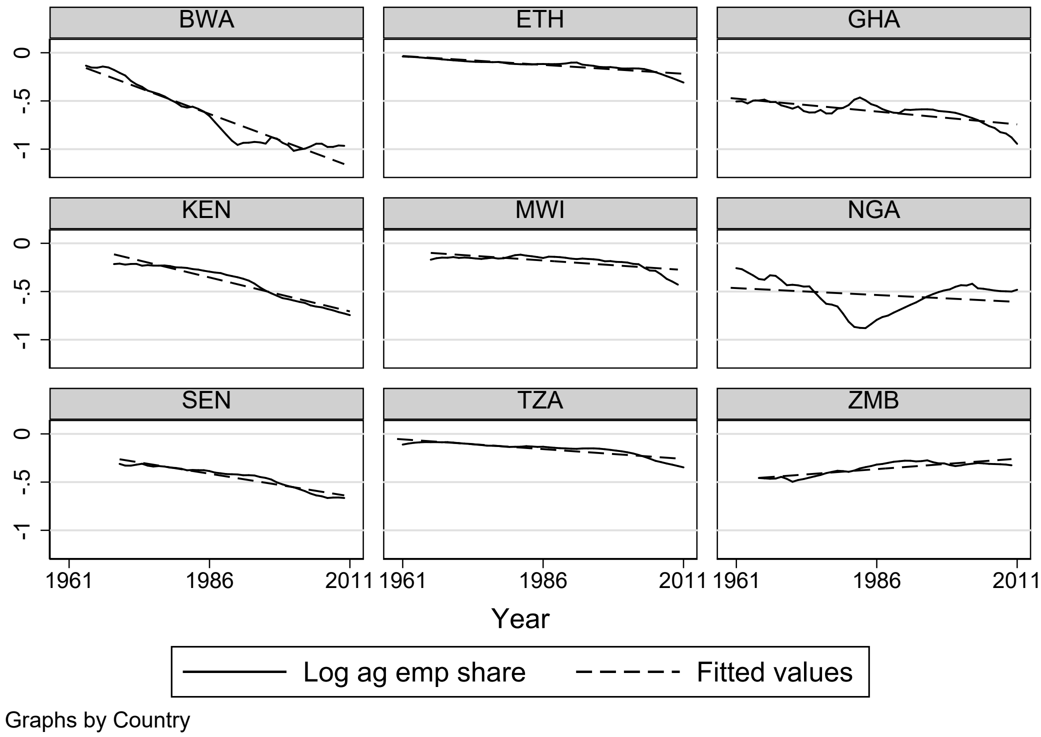

Figure 2: Log agricultural employment shares, with time trends

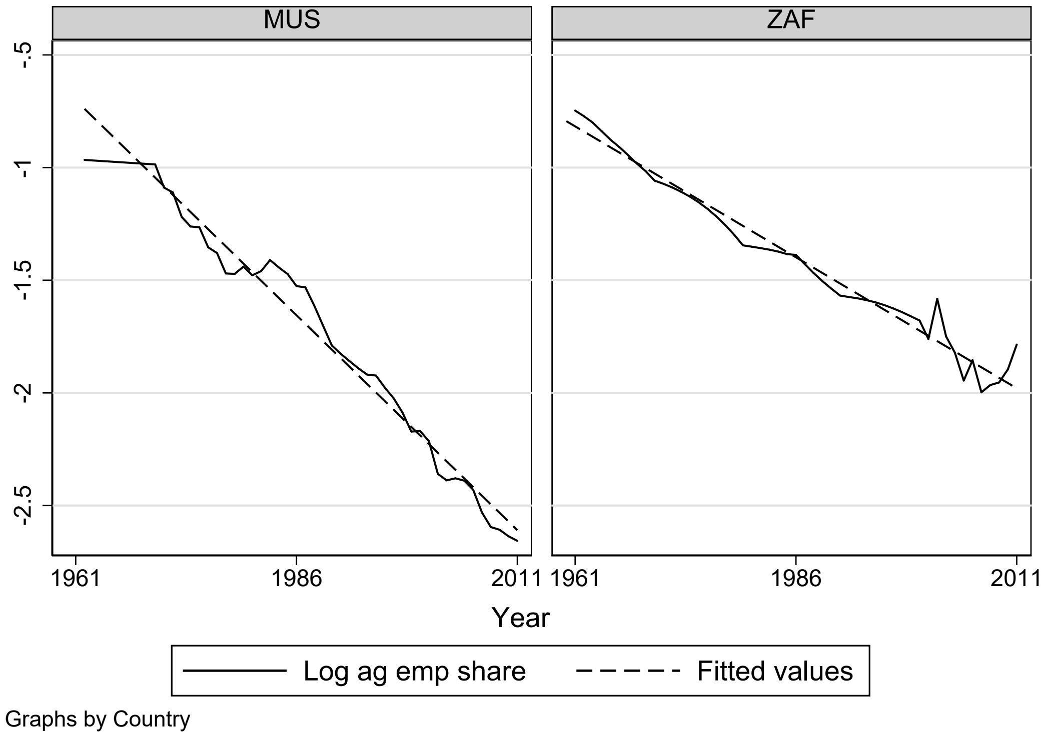

Figure 3: Log agricultural employment shares, with time trends, Mauritius and South Africa

It will be useful to have a single numerical measure of the rate of structural transformation. We make the assumption that the employment share of agriculture ℓ_a declines geometrically, given by the equation $\dot{\ell_a} = -\eta \cdot \ell_a$. We use 100η as our country-specific measure of the rate of structural transformation, obtained by regressing the log employment share on a time trend:

$$\log \ell_a(i,t) = \mu(i) - \eta(i) \cdot t + \varepsilon(i,t)$$

where i is the country index and t is time. The higher is η, the faster the rate of structural transformation. The higher is the R^2 of this regression for a given country, the better is our assumption that the employment share declines geometrically.

The estimates of η are presented in Table 1, ranked from fastest (Mauritius) to slowest (Zambia). We can see how well geometric decline fits the data using the R^2 column: clearly this approximation fits some countries much better than others. In section 7, we will compare the rates of structural transformation obtained in various simulations to those given in table 1.[7]

[7] Note that the suggested measure may work poorly when structural transformation is front-loaded — very fast early on — as can happen if the capital account is opened.

Country	100η	Std Err	R^2
Mauritius	3.81	0.099	0.973
South Africa	2.32	0.054	0.974
Botswana	2.17	0.098	0.915
Kenya	1.41	0.060	0.931
Senegal	0.94	0.044	0.921
Ghana	0.53	0.060	0.612
Tanzania	0.41	0.030	0.784
Malawi	0.39	0.058	0.517
Ethiopia	0.36	0.024	0.831
Nigeria	0.29	0.152	0.066
Zambia	-0.43	0.042	0.707

Table 1: Rates of Structural Transformation

This table shows rates of structural transformation, obtained by regressing the log of the agricultural employment share on a time trend (see the main text). We also report the standard error of the coefficient on the time trend, and the explanatory power of the trend for each country, as reflected in the R^2. Source: authors' calculations.

4 The model

This section describes a small open economy model with two sectors, in which the outputs of both sectors can be traded on world markets, and hence their relative price is determined by world prices. We assume there is a rural sector which produces an agricultural good, and co-exists with an emerging urban 'non-agricultural' sector that produces a composite good.[8] The two sectors, agriculture and non-agriculture ('manufacturing'), will be denoted by the subscripts a and m respectively. We treat the non-agricultural good as the numéraire, and the fixed relative price of the agricultural good is denoted by p_a.

Time is continuous, with an infinite time horizon. There is no uncertainty, allowing us to focus on the medium-run transitional dynamics as they unfold over decades. We model the optimization problem of a representative household that cannot borrow or lend internationally (this last assumption will be relaxed later). We consider the population as distributed among identical households or dynasties, which grow in size at a constant rate n, so $L(t) = L(0)\exp(n \cdot t)$. Each member of the household supplies one unit of labour inelastically.

The representative household's objective function is given by:

$$\int_0^\infty v(x(t), p_a) \cdot L(0) \cdot \exp(-(\rho - n) \cdot t)dt \tag{1}$$

where $v(x(t), p_a)$ is indirect utility, $x(t)$ is nominal expenditure and p_a is the relative price of the agricultural good. $\rho > 0$ is the subjective discount rate. In what follows, we sometimes

[8]At constant prices, this composite good can be interpreted as a fixed bundle of manufacturing goods and services. To keep the analysis simple, we abstract from the distinction between manufacturing and services in what follows.

suppress the time argument when there is no loss of clarity.

The representative household chooses the path of expenditure x to maximize lifetime welfare, given an equation for the evolution of assets and a no-Ponzi condition. The household earns a return on assets denoted by r and the stock of assets per capita is denoted a. Land income is distributed equally between households and the amount per head is given by b. The evolution of assets per capita is given by:

$$\dot{a} = w + b + r \cdot a - x - n \cdot a \tag{2}$$

where w is the wage. A standard no-Ponzi condition ensures that the lifetime budget constraint is well defined:

$$\lim_{t \to \infty} \left[a(t) \cdot \exp \left(- \int_0^t (r(s) - n) ds \right) \right] \geq 0 \tag{3}$$

We will assume that intratemporal preferences are Stone-Geary, as in Kongsamut et al. (2001). The indirect utility function will be:

$$v(x(t), p_a) \equiv \frac{1}{1-\sigma} \left[\frac{x(t) - p_a q}{p_a^{\gamma}} \right]^{1-\sigma}$$

These preferences are a special case of the class that Alder et al. (2019) call 'intertemporally aggregable' (IA). IA preferences have the attractive property that intertemporal decisions do not depend on the distribution of income across households. The asymptotic elasticity of intertemporal substitution is given by $1/\sigma$, where $\sigma \neq 1$ and we assume throughout that $\rho > n + (1-\sigma)g_m$ so that lifetime utility is bounded, where g_m is the growth rate of labour-augmenting efficiency in the non-agricultural sector.

Our special case corresponds to Stone-Geary preferences over the two goods, so the direct utility function is $1/(1-\sigma)[(c_a - q)^{\gamma} c_m^{1-\gamma}]^{1-\sigma}$ where c_a is consumption per capita of the agricultural good, c_m is consumption per capita of the non-agricultural good, $0 < \gamma < 1$, and the subsistence parameter $q > 0$ ensures that the budget share of the agricultural good declines as total consumption expenditure rises.[9] If q is high enough, these preferences are likely to restrain saving in the early years of a transition. This seems plausible for low-income countries, and is consistent with evidence that investment rates in sub-Saharan African countries are not high (Melina and Portillo 2018).

We can write the current-value Hamiltonian for the household's problem as:

$$H = v(x, p_a) + \lambda(w + b + r \cdot a - x - n \cdot a)$$

[9] As is standard in models with these preferences, we assume productivity is sufficiently high that consumption of the agricultural good is always higher than the subsistence level.

The static and dynamic conditions for the optimality of a candidate interior solution are:

$$\frac{\partial H}{\partial x} = \frac{\partial v}{\partial x} - \lambda = 0 \tag{4}$$

$$\frac{\partial H}{\partial a} = (\rho - n)\lambda - \dot{\lambda} = (r - n)\lambda. \tag{5}$$

together with the transversality condition

$$\lim_{t \to \infty} [\exp(-(\rho - n) \cdot t) \cdot \lambda(t) \cdot a(t)] = 0 \tag{6}$$

Following Acemoglu (2009, pp. 294-6) it can be shown that household maximization, including the transversality condition (6), implies that the no-Ponzi condition (3) in the original problem will hold with equality.

For present purposes, rather than derive an explicit dynamic equation in nominal consumption expenditure $x(t)$, it will be convenient to work with the costate variable $\lambda(t)$. This has a direct interpretation as the marginal utility of wealth.

We now turn to the production equilibrium, which is the outcome of decisions by perfectly competitive firms, using production technologies with constant returns to scale. Non-agricultural firms produce output using capital K_m and labour L_m. Agricultural firms produce output using capital K_a, labour L_a and land B_l. As we discuss shortly, the role of the fixed factor, land, ensures that the agricultural sector never closes down completely.

The production technologies are given by:

$$Y_a = G\left(K_a, A_a \cdot L_a, B_l\right)$$
$$Y_m = F\left(K_m, A_m \cdot L_m\right)$$

where A_a and A_m are the sectoral levels of labour-augmenting efficiency, growing at the (exogenous and constant) rates g_a and g_m respectively. Aggregate output is given by:

$$Y \equiv p_a \cdot Y_a + Y_m \tag{7}$$

Since we restrict attention to cases where the relative price p_a is constant over time, Y can also be taken as a measure of constant-price real GDP, although our focus will be effects on welfare rather than on real GDP.

We assume that labour is perfectly mobile between the two sectors, and in each sector, receives a wage equal to its marginal product. For the sectoral equilibrium at each instant, wages are equalized:

$$w_m = w_a$$
$$F'_{L_m} = p_a \cdot G'_{L_a}$$

All capital will be fully utilized in equilibrium, so K_a and K_m sum to the total capital stock K. Capital can move freely between sectors, so that returns are equalized at each instant:

$$F'_{K_m} = p_a \cdot G'_{K_a} \tag{8}$$

The role of land in the model is worth noting. Without land, the economy we have described would be a dynamic version of the 2×2 trade model. For dynamic analysis, that model has the drawback that the economy will be completely specialized in one sector or the other for some ranges of the capital-labour ratio. This implies that the model would switch regimes over time. Including a role for land in agriculture has the advantage that, although agriculture's share of employment and output will approach zero asymptotically, the sector will never close down completely. This means that the economy can be described by the same set of equations throughout, which simplifies the numerical solution of the model.

We now consider the use of capital, which firms rent from households. Given fixed prices, firms equate the value of the marginal product of capital to the sum of the interest rate and depreciation, in the usual way, and hence:

$$F'_{K_m} = p_a \cdot G'_{K_a} = r + \delta \tag{9}$$

Assuming (for now) that there is no international borrowing or lending, the capital stock per worker $k \equiv K/L$ is equal to assets per worker, and hence

$$k = a \tag{10}$$

at every instant. Combined with equation (2), capital per worker will evolve as $\dot{a} = y - x - (n + \delta) \cdot a$ and equation (5) for the evolution of the costate can be rewritten as:

$$\frac{\dot{\lambda}}{\lambda} = \rho - r = \rho - (f'(k_m) - \delta) \tag{11}$$

where $k_m \equiv K_m/(A_m \cdot L_m)$ and $f(k_m) \equiv F(k_m, 1)$ is the non-agricultural production function in effective worker terms. Note that the two differential equations just stated link the production equilibrium to the household side of the model, partly through equation (4).

We now discuss the balanced growth path. As is well known, balanced growth paths in multi-sector models often require a knife-edge parameter restriction, or restrictions on the production technologies (for example, Kongsamut et al. (2001) and Ngai and Pissarides (2004)). Our model avoids this, as it implies that the non-agricultural sector ultimately dominates. This outcome will require an inequality condition on parameters, rather than a knife-edge restriction. It allows us to specify production technologies with output-capital elasticities that differ between the two sectors, consistent with the evidence in Eberhardt and Teal (2013b).

Under an assumption stated later, the economy will converge to an asymptotic balanced growth path in which the agricultural employment share approaches zero. Output per worker and capital per worker grow at g_m, the rate of labour-augmenting technical progress in non-agriculture. When needed, we can normalize all the endogenous per capita variables in effective worker terms, dividing them by A_m. The normalized costate variable $\hat{\lambda}$ is defined by $\hat{\lambda} \equiv \lambda A_m^{\sigma}$.

For the simulations, we adopt a Cobb-Douglas production function in agriculture, which has often been adopted in the empirical literature.[10]

$$Y_a = X_a \cdot B_l^{\alpha} \cdot K_a^{\beta} \cdot (A_a \cdot \ell_a \cdot L)^{1-\alpha-\beta} \tag{12}$$

where X_a is agricultural TFP (used for the productivity increase considered later), ℓ_a is the employment share of agriculture, and other variables are as defined earlier. Given evidence, including Chirinko (2008), Gechert et al. (2019) and Knoblach et al. (2020), that the elasticity of substitution is less than one for the US economy, we adopt a CES production function in non-agriculture:

$$Y_m = X_m \left(\delta_p K_m^{-\nu} + (1-\delta_p)(A_m \cdot (1-\ell_a) \cdot L)^{-\nu}\right)^{-\frac{1}{\nu}} \tag{13}$$

where X_m is non-agricultural TFP, and the elasticity of substitution between capital and labour is given by $\sigma_{KL} \equiv 1/(1+\nu)$.

The agricultural sector disappears asymptotically, and the ratio of land to labour in that sector approaches infinity. With this in mind, for the purpose of the numerical solution, it will be useful to work with a transformation of the land variable, and an additional normalization variable with a known path. The transformation of the land variable is given by:

$$k_l \equiv B_l \cdot A_a^{\frac{1-\alpha-\beta}{\alpha}} \Big/ \left(A_m^{\frac{1-\beta}{\alpha}} \cdot \ell_a \cdot L\right) \tag{14}$$

and the additional normalization variable z is given by:

$$z \equiv A_a^{\frac{1-\alpha-\beta}{\alpha}} \Big/ \left(A_m^{\frac{1-\beta}{\alpha}} \cdot L\right) \tag{15}$$

These two equations together imply:

$$k_l \cdot \ell_a = B_l \cdot z \tag{16}$$

while, after some algebra, the agricultural production function (12) can be rewritten in normalized terms as:

$$y_a = X_a \cdot k_l^{\alpha} \cdot k_a^{\beta}$$

where $y_a \equiv Y_a/(A_m \ell_a L)$ and $k_a \equiv K_a/(A_m \ell_a L)$. The transformed land variable k_l will asymptotically approach a finite constant, even though the ratio of land to labour in agri-

[10]Block (2014, p. 377) describes the assumption of a constant returns Cobb-Douglas production function in agriculture as 'repeatedly validated' in empirical studies.

culture approaches infinity as the agricultural employment share approaches zero. The use of a transformed land variable then allows us to solve the model in a simple way. Similarly,

$$y_m = X_m \left(\delta_p k_m^{-\nu} + (1-\delta_p)\right)^{-\frac{1}{\nu}} \tag{17}$$

where $y_m \equiv Y_m/(A_m(1-\ell_a)L)$ and $k_m \equiv K_m/(A_m(1-\ell_a)L)$.

Note that the dynamic path of z is exogenous and known. Based on its definition, consider the following inequality restriction on parameters:

$$\left(\frac{1-\alpha-\beta}{\alpha}\right) g_a < \left(\frac{1-\beta}{\alpha}\right) g_m + n \tag{18}$$

where n, g_m and g_a are the growth rates of population, A_m and A_a, respectively. When this inequality holds, z will asymptotically converge to zero:

$$\lim_{t\to\infty} z(t) = 0$$

Since B_l is fixed and z follows an exogenous path, asymptotically approaching zero at a known rate, so will the product of k_l and ℓ_a as implied by equation (16). Since k_l approaches a finite constant, ℓ_a approaches zero. The relative importance of agriculture declines and, asymptotically, the growth path will approach that of the standard one-sector Ramsey model with efficiency growth at rate g_m.

Note that we do not explicitly model the price of land. This asset price is a jump variable, which at time zero will jump on to an equilibrium path. Along this path, overall returns from holding land will be continuously equal to returns on other assets, given capital gains or losses on the value of the land (see, for example, Roe et al. 2010, pp. 81-82). But since the intertemporal decisions and static allocations of interest to us are independent of the price of land along the equilibrium path, we do not need to model the price explicitly. The land price path implicit in a solution for the other variables could be computed if needed.

5 Some variations

We now discuss some variations on the basic model. These generalize the model in some respects, often with implications for the rate of structural transformation.

5.1 Time-varying population growth

The rate of population growth plays an important role in the rate of structural transformation. Since agricultural land is fixed, population growth places downwards pressure on wages, prompting workers to leave the agricultural sector more quickly, as in Ying (2014). This means that assumptions on the population growth rate play an important role in our analysis.

For low-income countries in Africa, the current rate of population growth is likely to be higher than the steady-state rate. To accommodate this, we allow for a time-varying population growth rate. For simplicity, given the aims of the paper, we assume that the population growth rate declines exogenously towards a steady-state rate. The online appendix shows how to formulate the new optimal control problem in which:

$$\dot{n} = \chi(n^* - n) \tag{19}$$

where n is a time-varying population growth rate that tends at rate χ to a steady-state value n^* as $t \to \infty$. As the appendix shows, the solution method for the new optimal control problem reduces to a simple extension of our previous model.

5.2 Taxes on profits

Suppose that profits are taxed in both sectors, at a common rate τ. This could be interpreted as a formal tax, or the outcome of corruption and otherwise imperfect institutions, such as a risk of expropriation. As in the standard one-sector analysis, the introduction of a capital tax reduces steady-state capital intensity and the rate of capital accumulation. In our two-sector case, this also slows down structural transformation.

Capital taxes are introduced by modifying (9) to:

$$r = (1-\tau)(F'_{K_m} - \delta) = (1-\tau)p_a(G'_{K_a} - \delta)$$

so that (11) becomes:

$$\frac{\dot{\lambda}}{\lambda} = \rho - (1-\tau)(f'(k_m) - \delta), \tag{20}$$

where we have assumed that depreciation is tax-deductible.[11] For simplicity, we assume that the proceeds of the tax are reimbursed to households as a lump sum, so the asset accumulation equation is unchanged.

5.3 A version with debt

Thus far, we have assumed that the economy is open to trade but closed to international capital flows. We now briefly describe how the model can be extended to the case of partial capital mobility. We assume that domestic households can borrow or lend internationally at an interest rate that depends on the aggregate stock of debt. Assuming a debt-elastic interest rate has become a common approach in open economy macroeconomics: see Bouza and Turnovsky (2012) for an example, or Uribe and Schmitt-Grohé (2017) for a textbook treatment.

Noting that our assets variable a should now be thought of as net asset holdings, the domestic capital stock minus debt, equation (10) becomes

$$a = k - d \tag{21}$$

[11] For the relevant assumptions see, for example, Barro and Sala-i-Martin (2004, pp. 144-145).

where d is per-capita foreign debt. The evolution of net assets per capita remains:

$$\dot{a} = w + b + r(d/y) \cdot a - x - n \cdot a \tag{22}$$

except now that the interest rate $r \equiv r(d/y)$ is debt-elastic where (d/y) is the aggregate debt-output ratio. At each instant, the interest rate will be equal to the (after-tax) marginal product of capital minus depreciation, given profit maximization by domestic firms. Thus

$$(1 - \tau)\left(f'(k_m) - \delta\right) = r\left(\frac{k - a}{y}\right). \tag{23}$$

In this model, capital is traded and can be imported instantaneously without limit as in, for example, Obstfeld (1989); hence both k and d are jump variables. They will jump to ensure that (23) holds. The state variable in the model is still net asset holdings, a, whose evolution is pinned down by equation (22) above. The choice of a specific function for $r(.)$ will be discussed in section 8, which presents simulations of the version with debt.

6 Simulation assumptions

In the simulations, we select parameters to match relevant characteristics of sub-Saharan African countries in the Africa Sector Database (ASD) of de Vries et al. (2015), around 2010; see in particular their Appendix Table C5. We are not seeking to match historical data for any individual country, or to make predictions about future growth, since the model we adopt is too stylized for that to be worthwhile.

In the simulations, we adopt the version of the model in section 5 that allows time-varying population growth. In particular, we assume that the population growth rate declines over time starting from an initial level $n(0)$ and converging geometrically to its steady-state value n^*. We set initial population growth $n(0) = 0.027$ by calculating the annual population growth rate over 2000-2010 for the ASD countries, the median of which is 2.7%. The steady-state population growth rate is taken to be 1.0% so $n^* = 0.01$. The population data are taken from version 9.1 of the Penn World Table (for a recent discussion of the PWT, see Feenstra et al. 2015).

We consider an economy in which agriculture initially employs 56% of the labour force, based on the median value for the eleven ASD countries in 2010. We assume a discount rate of $\rho = 0.06$, a depreciation rate of $\delta = 0.06$, and $\sigma = 2$, corresponding to an (asymptotic) elasticity of intertemporal substitution of 0.5. With the exception of the discount rate, these are standard values in the literature. We choose a high discount rate partly because this seems appropriate for a developing country, and will examine sensitivity to this assumption later in the paper.

The intratemporal Stone-Geary preferences have two parameters: the asymptotic food expenditure share γ and the subsistence parameter q. We select $\gamma = 0.20$ which is the food share for South Africa in FAO data. For q, we use an iterative procedure to ensure that, in our benchmark economy, the initial budget share for food matches the median value in FAO data (various years), namely 0.51.[12]

For the agricultural production function, we adopt the output elasticities estimated by Martin and Mitra (2001) for their Cobb-Douglas, constant returns to scale case. They estimate an output-capital elasticity of 0.12, an output-land elasticity of 0.24, and hence an output-labour elasticity of 0.64. These are also the parameters used for agricultural production in Irz and Roe (2005).[13]

For the elasticity of substitution between capital and labour in non-agriculture, the survey by Chirinko (2008) argues that the weight of evidence for the whole US economy favours 0.40 to 0.60, while the meta-regression in Knoblach et al. (2020) gives a range of 0.45–0.87 for the US economy, and indicates that estimates for industry would be similar. With these findings in mind, we adopt $\sigma_{KL} = 0.60$. We calibrate the distribution parameter in the CES technology so that the steady-state capital share for the sector (and the asymptotic share for the economy as a whole) will be equal to 0.30. As we will see later, this assumption plays a key role in the analysis.

The sectoral rates of labour-augmenting technical progress will be important in determining the rate of structural change. We set g_a to 0.015 and g_m to 0.010.[14] Combined with our other assumptions, these values ensure a rate of structural change comparable to those in Table 1, as we discuss further below. Note that our parameter assumptions ensure that (18) holds, as required for asymptotic balanced growth. That can be achieved even when the rate of technical progress in agriculture exceeds that in non-agriculture. This is because other forces — capital accumulation, and labour force growth in the context of fixed land — work to increase the non-agricultural sector's share in value added.

In the version of the Stone-Geary economy that we consider, technical progress eventually renders the subsistence parameter q irrelevant. The balanced growth path is asymptotic, as in one-sector models with Stone-Geary preferences; see, for example, Ohanian et al. (2008).

For the initial capital-output ratio, we use a figure of 1.23, based on calculations for low-income aid recipients in Carter et al. (2015).[15] Under our assumptions, the steady-state capital-output ratio in the benchmark economy is 2.14. This implies that the capital-output ratio in our benchmark economy will not quite double in the course of converging to the steady-state; for comparison, Obstfeld (1999) studied a three-fold increase.

[12]The iterative procedure is needed because computing the initial budget share requires knowledge of initial consumption expenditure, which can be established only by solving numerically the system of dynamic equations.

[13]In practice the parameters are likely to vary across countries (Eberhardt and Teal 2013a). Vollrath (2011) and Eberhardt and Vollrath (2018) find that structural transformation and development patterns are sensitive to the output-labour elasticity in agriculture, corresponding to different crop types; we intend to explore this in further work.

[14]The figure for efficiency growth in agriculture may seem high, but TFP growth in sub-Saharan Africa has increased since the early 1980s (Block 2014).

[15]They used a perpetual inventory calculation based on investment and output data from the Penn World Table. Their calculation assumed a one-sector economy, but there is no straightforward way to generalize this to our two-sector setting.

Parameter/Calibration Target	Baseline Value
$n(0)$, initial population growth	0.027
n^*, steady-state population growth	0.010
χ, convergence rate of population growth	0.10
ρ, discount rate	0.06
δ, depreciation rate	0.06
τ, tax rate	0.00
σ, inverse of elasticity of intertemporal substitution	2.00
γ, asymptotic food expenditure share	0.20
α, output-land elasticity in agriculture	0.24
β, output-capital elasticity in agriculture	0.12
g_a, technical progress in agriculture	0.015
g_m, technical progress in non-agriculture	0.010
$\sigma_{KL} \equiv 1/(1+\nu)$, non-ag. elasticity of substitution between K and L	0.60
Steady-state capital share (gives δ_p)	0.30
Initial budget share of food expenditure (gives q)	0.51
Initial employment share, agriculture (gives initial z and a)	0.56
Initial capital-output ratio (gives initial z and a)	1.23

Table 2: Parameter values and calibration targets

Source: authors' choices, see main text.

In our baseline simulations, we consider the version of the model without debt; the calibration of the additional parameters related to debt is discussed in section 8. To carry out the simulations, we use the relaxation algorithm of Trimborn et al. (2008). This algorithm allows us to solve for the paths of all variables in the system of equations, without the need for the approximations around the steady-state that were used in Obstfeld (1999) and related papers. This is a particular gain when we consider models where convergence to the steady-state is slow, as can arise given Stone-Geary preferences and a multi-sector structure. Atolia et al. (2010) emphasize the relevance of the convergence speed, and note that the approximation errors introduced into simulated growth models by linearization can be especially important for welfare calculations.

Our assumptions imply that structural change continues indefinitely, with the share of the agricultural sector in total employment approaching zero asymptotically. The growth rate of GDP per capita will asymptotically approach the rate of efficiency growth in non-agriculture, g_m. When solving the system of equations numerically, we convert the system into quantities measured in efficiency units: capital, sectoral outputs, total output and consumption are divided by the level of efficiency in the non-agricultural sector. Also note that in the associated system the subsistence parameter q will also be rewritten in terms of efficiency units. Although q is assumed constant, its normalized version declines over time: technical progress gradually renders the subsistence parameter irrelevant.

7 Simulation results

In what follows, we consider three cases. These are the benchmark; adjustment to higher TFP in agriculture; and adjustment to higher TFP in non-agriculture. As mentioned earlier, we can see the posited TFP increases as a reduced-form way to capture sector-specific investments, such as state-provided infrastructure in rural or urban areas.

Rather than consider an instantaneous jump in sectoral TFP, we allow the TFP increase to feed through gradually. In the case of a 10% agricultural TFP shock, for example, we adopt

$$\dot{X}_a(t) = \kappa(X_a^* - X_a(t))$$

where $X_a(0) = 1$ and $X_a^* = 1.1$. For all the TFP shocks considered in the paper, we set $\kappa = 0.10$ and assume an ultimate increase of 10%.[16]

We first look at the paths of the agricultural employment share, which are shown in Figure 4a. The solid line is the baseline case, the dashed line arises under a gradual gain in agricultural TFP, and the dot-dashed line arises under a gradual gain in non-agricultural TFP. In Figure 4b, we plot the logarithms of the agricultural employment shares. Beyond the first ten years, these are roughly straight downward-sloping lines, suggesting that the model can match the geometric decline in the agricultural employment share that we saw in some of the countries considered in section 3.

In the baseline case, the average rate of geometric decline over the 60-year span shown in the figures (100η) is 1.25, which would place this economy fifth among the ASD countries listed in Table 1. A calculation based on a shorter interval would sometimes show a faster rate of structural transformation, as is evident from Figure 4b. Using the first 30 years, we obtain 1.71 for the rate, which would place the economy fourth in Table 1. The rates of structural transformation in the data, shown in Table 1, can be compared to those obtained from alternative parameter choices, shown in Table 3.

Using Table 3, we can examine the sensitivity of the rate of structural transformation to parameter choices. The rate of transformation is especially sensitive to capital taxes and the discount rate, but relatively insensitive to slower rates of technical progress. Calibration to match a slightly higher steady-state capital share greatly hastens structural transformation: as capital accumulation proceeds, sectoral structure is influenced by the relative capital intensities of the two sectors. On the other hand, increasing the elasticity of substitution between capital and labor in non-agriculture somewhat reduces the rate of structural transformation.

A slower demographic transition means faster population growth which, by interacting with the fixed stock of land, then prompts faster structural transformation. The last row suggests that the rate of transformation in the baseline is influenced only slightly by Stone-Geary preferences: if we calibrate the model with a lower initial budget share of food, structural transformation is slightly faster, since capital accumulation is less constrained by

[16] For the case of instantaneous changes in sectoral TFP, see the working paper version of this research, Monteforte et al. (2019).

Variation from baseline parameters	$100\eta_{\text{m30}}$	$100\eta_{\text{m60}}$
None	1.71	1.25
Capital taxes: $\tau = 0.20$	0.95	0.86
Higher initial capital share $= 0.35$	3.09	1.99
Slower growth: $g_m = 0.005$, $g_a = 0.01$	1.72	1.00
Higher discount rate: $\rho = 0.08$	1.00	0.88
Higher elast. of substitution: $\sigma_{KL} = 0.99$	1.47	1.12
Slower demographic transition: $\chi = 0.05$	2.05	1.50
Lower initial food share expenditure target, 0.25	1.89	1.30

Table 3: Simulated rates of structural transformation

The rates of structural transformation implied by the model simulations are the counterpart to empirical rates of structural transformation given in Table 1. The quantities η_{m30} and η_{m60} give the rates of structural transformation over the first thirty and first sixty years of the simulations, respectively, using the measure described in Section 3 above. Source: authors' simulations.

the subsistence parameter in food consumption.

Next, we return to the effects of sector-specific productivity growth, comparing the baseline (one set of outcomes) with agricultural TFP improvement (the second set) and non-agricultural TFP improvement (the third set). We look first at the path of capital-output ratios, shown as the upper panel in Figure 5. Note that, immediately after time zero, productivity improvements may lead the initial capital-output ratio to fall: the initial capital stock is fixed, while output has increased. An agricultural productivity improvement does not promote aggregate capital accumulation, because the change in technology leads the agricultural sector to expand and it is less capital-intensive than non-agriculture. In the case of a non-agricultural productivity improvement, it is the non-agricultural sector which expands faster, the marginal product of capital increases, and capital is accumulated more rapidly than in the baseline case. The faster accumulation of capital drives faster wage growth, which can be seen in the lower panel of Figure 5.

The paths for saving rates are shown in the upper panel of Figure 6. The saving rate in the benchmark economy is comparable to the gross investment rates of 15-19% in sub-Saharan Africa documented in Melina and Portillo (2018, Table 5). The effect of a non-agricultural TFP gain on the demand for capital causes a higher saving rate in that case. But the response is muted, and it is also noticeable that the saving rates do not show the initial spike that often appears in the one-sector Ramsey model. In this two-sector model with Stone-Geary intratemporal preferences, the presence of subsistence consumption of the agricultural good keeps initial saving relatively low.

There is still a peak in the initial growth rate, as in the lower panel of Figure 6, but this is again muted relative to the one-sector case.[17] In the case of the agricultural productivity improvement, the growth rate varies only modestly, given the slower accumulation of capital in this case.

[17]For the one-sector case see, for example, Barro and Sala-i-Martin (2004, pp. 116-118).

Naturally in the present model, a sector-specific TFP gain will increase lifetime welfare. We will describe the welfare effects in various experiments, summarized in Table 4. This shows the welfare gain from a 10% increase in agricultural TFP, and the percentage increase in non-agricultural TFP that would yield the same welfare gain. This is always smaller than 10%, indicating that TFP gains in non-agriculture are more valuable. Only for the case of a high discount rate does an agricultural TFP shock come close to generating a larger welfare gain than the same shock to non-agriculture.

Variation from baseline parameters	Welfare Gain from 10% TFP shock in Agriculture (%)	Size of Welfare-equivalent TFP shock in Non-agriculture (%)
None	3.17	7.31
Capital taxes: $\tau = 0.20$	3.39	8.22
Higher initial capital share $= 0.35$	2.30	4.56
Slower growth: $g_m = 0.005$, $g_a = 0.01$	3.20	6.95
Higher discount rate: $\rho = 0.08$	3.38	9.87
Higher elast. of substitution: $\sigma_{KL} = 0.99$	3.37	8.04
Slower demographic transition: $\chi = 0.05$	3.06	6.62
Lower initial food share expenditure target, 0.25	3.16	6.62

Table 4: Welfare effects of TFP shocks

The first column describes the parameters used for each simulation. For these parameters, the second column gives the percentage increase in consumption expenditure along the path obtained without a shock that would be required to produce the same welfare gains as a 10% shock to agricultural TFP. The third column gives the size of the non-agricultural TFP shock that would be required to achieve the same welfare gains. For example, at the baseline, a 7.31% shock to non-agricultural TFP produces the same welfare improvement as a 10% shock to agricultural TFP. Source: authors' simulations.

Starting from our benchmark economy, a 10% increase in agricultural TFP has the same effect on lifetime welfare as increasing baseline consumption expenditure by 3.17% at every instant (all reported welfare gains use this consumption-equivalent metric, and will be stated to one decimal place). A 10% increase in non-agricultural TFP has the same effect as increasing baseline consumption expenditure by 4.40%. Although non-agriculture initially accounts for a lower share of employment, it is expanding over time, so that productivity gains in non-agriculture are more valuable than in agriculture.

The precise extent of the difference is sensitive to the capital intensity of the non-agricultural sector. The higher that intensity, the more sensitive is sectoral structure to the accumulation of capital.[18] If we calibrate the distribution parameter of non-agriculture's CES production function so to give a steady-state capital share of 0.35 rather than 0.30, the case for making non-agriculture a priority strengthens. In this economy, a 10% increase in agricultural TFP is equivalent to increasing baseline consumption expenditure by 2.30%.

[18] Acemoglu and Guerrieri (2008) emphasized the role of sectoral differences in factor proportions in shaping structural transformation and aggregate growth.

In contrast, a 10% increase in non-agricultural TFP has the same effect on welfare as increasing baseline consumption expenditure by 5.13%.

We next examine whether agriculture becomes a higher priority if we choose parameters that slow the rate of structural transformation. We consider the benchmark economy but reduce g_a to 0.01 and g_m to 0.005. In this setting, the average rate of geometric decline of the agricultural employment share over sixty years falls to $100\eta = 0.88$, compared to 1.25 earlier. But a comparison of welfare effects still favours non-agriculture. A 10% increase in agricultural TFP is equivalent to increasing baseline consumption expenditure by 3.20%, in contrast to the 4.68% figure we obtain with a 10% increase in non-agricultural TFP.

The transformation is also slowed if we assume that profits are taxed in both sectors at a rate τ, as discussed in section 5. As noted earlier, this could be interpreted as a formal tax, or the outcome of imperfect institutions. Given our broad interpretation of the tax we choose a value of $\tau = 0.20$. Under that assumption, the average rate of geometric decline of the agricultural employment share over sixty years falls to $100\eta = 0.86$, compared to 1.25 in the benchmark case. As expected, taxes on profits slow down structural transformation. This would put the economy in seventh place in Table 1, but leads to gross investment rates in the region of 11% of GDP, lower than the rates in Melina and Portillo (2018). Not surprisingly, the slower rate of structural transformation brings the welfare gains closer together. Again in consumption-equivalent terms, the welfare gains we obtain are 3.39% and 4.19% for 10% increases in agricultural and non-agricultural TFP respectively.

As noted earlier, increasing the discount rate favours agriculture in two ways. First, by giving more weight in the welfare calculation to near-term outcomes, it gives more weight to times when agriculture accounts for a high share of employment. Second, a higher discount rate — greater impatience — leads households to save less. Lower investment means slower structural transformation, again tipping the balance towards agriculture. With a discount rate of $\rho = 0.08$, we find that the welfare effects of 10% increases in agricultural and non-agricultural TFP are almost the same: equivalent to raising baseline consumption expenditure by 3.38% and 3.41% respectively. In the baseline case, the implied investment rate increases from 11% at time zero to 15% along the asymptotic balanced growth path. Hence, investment is initially lower than the rates seen in the data.

In the baseline, the population growth rate falls quite rapidly, corresponding to a fast demographic transition. A slower transition, reducing χ from $\chi = 0.1$ to $\chi = 0.05$, means the population growth rate falls more slowly. This has an effect on the rate of structural change, which over sixty years increases to 1.50 from 1.25 in the baseline. This leads the welfare gains from productivity shocks to diverge: 10% increases in agricultural and non-agricultural TFP are equivalent to increasing baseline consumption expenditure by 3.06% and 4.70% respectively.

Finally, we examine how the assumed Stone-Geary preferences influence our results. To do this, we lower the calibration target for the initial share of expenditure on food, from 0.51 to 0.25. This greatly reduces the Stone-Geary effect, since the parameter determining the minimum consumption of food falls by over 80%. This leads to a slightly faster structural transformation, since capital accumulation is less constrained. Despite this, the case for making non-agriculture the priority actually strengthens. The welfare gains from 10% increases in agricultural and non-agricultural TFP are equivalent to increasing baseline consumption expenditure by 3.16% and 4.86% respectively.

8 Capital mobility

In this section, we consider simulations with debt, where the economy can borrow or lend internationally. The relevant interest rate depends on the aggregate debt-output ratio, as discussed in section 5.

When analysing the role of debt, we can distinguish two sets of questions that could be asked. The economist's question is: what is the effect of improved access to debt on model outcomes *given the structural parameters* listed in table 2? The policy-maker's question is: what is the effect of improved access to debt on model outcomes *given the parameters and all of the calibration targets* listed in table 2? In other words, the economist often wants to investigate specific parameter changes while holding other structural parameters constant; the policy-maker might want to investigate the implications of changes in parameter assumptions, while keeping the calibrated model consistent with the observed data that they currently face.

For the policy-maker's question, the key calibration targets in question are the initial capital-output ratio and the agricultural employment share, which pin down the initial value of physical capital $k(0)$ regardless of whether debt is in the model.[19] The answer to this question is relatively conventional. Allowing borrowing leads to faster capital accumulation early in the growth path, leading to faster convergence and structural transformation.

The answer to the policy-maker's question is that allowing for debt, or varying the parameters that govern its role in the model, has relatively little impact on model outcomes. This is chiefly because, in the calibrated model, the initial level of physical capital in the simulations is essentially independent of our assumptions on debt. Nonetheless, the answer to the policy-maker's question is potentially important: if we wish to calibrate our model to particular observed moments in the data, so that it remains consistent with them, it might be that varying a specific parameter assumption can be shown to have only a limited effect on predicted outcomes.

It is easiest to begin with this second question, that of the policy-maker. We pin down the initial debt-output ratio by taking the median value for our eleven countries in 2010, using the data of Lane and Milesi-Ferretti (2018). This value is 0.2519, corresponding to the value for Ethiopia. Given that $k = a - d$ and the initial capital-output ratio is one of our calibration targets, this will pin down the initial level of the state variable, net assets $a(0)$.

We also need to specify the debt-elastic interest rate function. The form we adopt

[19]They also pin down $z(0)$ which reflects sector-specific productivity levels.

follows Schmitt-Grohé and Uribe (2003) quite closely:

$$r(d/y) = r^* + \psi\left(\exp(d/y - \Delta) - 1\right) = (1-\tau)(f'(k_m) - \delta). \qquad (24)$$

Here r^* is the world interest rate and ψ represents the semi-elasticity of the interest rate spread with respect to the debt-output ratio. Δ can be interpreted as the debt-output ratio where the interest rate equals the world rate; we would typically expect this to be negative, and it will be in our calibration.[20]

The extent of capital mobility is indexed by the ψ parameter. Perfect capital mobility would mean $\psi = 0$. The polar case where the economy is closed to capital flows would be $\psi = \infty$ and $\Delta = 0$, which, making debt the subject of (24), implies a debt level of zero. The last equality in equation (24) repeats equation (23) for convenience. Given that the initial debt-output ratio is pinned down by the data, and the calibration targets pin down $k(0)$ and the initial marginal product of capital, an assumption on ψ will imply an associated value of Δ in (24).

To set ψ, we consider previous work on emerging markets. Drawing on and providing further evidence for the findings of Rowland and Torres (2004), Clarida and Magyari (2016) report that an increase of 0.10 in the debt-output ratio induces an average increase in the interest rate spread of 70 basis points. In the context of equation (24), we would typically expect $\exp(d/y - \Delta) > 1$, so that $\psi = 0.07$ would be an upper bound consistent with Clarida and Magyari (2016). We start with $\psi = 0.07$ and then explore lower values.

Table 5 presents some outcomes for the baseline model without debt, and for the version with debt and various values of ψ. The introduction of debt does modify the results, mostly because the economy is then calibrated to an initial debt-to-output ratio which implies a lower level of initial net assets. But we can also see that varying the level of openness has only limited effects on the simulated outcomes. In the policy-maker's approach — where other structural parameters adjust to match the data — when the assumed ψ changes, Δ must also change to meet the model's calibration targets. This offsets the effects of the new ψ, and rates of structural transformation even decrease slightly with lower values of ψ.[21]

To answer the economist's question — the effects of parameter changes, keeping other structural parameters constant — we consider the following exercise. Using simulations that meet the calibration targets, figure 7 plots outcomes for two cases. In the first, $\psi = 0.07$ throughout. In the second, holding Δ constant, ψ starts at a value of 0.07 but falls to a value of 0.01 over time, corresponding to less costly international borrowing. We can see from panel 7a, which plots debt-output ratios, that the capital mobility shock leads to a substantial increase in steady-state debt. In turn, this promotes faster convergence to

[20] Schmitt-Grohé and Uribe (2003), in a business cycle framework, use a related specification but use the absolute level of debt rather than the debt-output ratio. The latter seems a natural modification for a growing economy.

[21] With this in mind, it would be interesting to explore a more complex version of the interest-elastic debt function (24) with an additional parameter. We leave this for future research.

Capital Mobility	$100\eta_{m30}$	Welfare Gains from 10% TFP shock in Agriculture (%)	Size of Welfare-equivalent TFP shock in Non-agriculture (%)
No debt ($\psi = \infty$)	1.711	3.170	7.311
$\psi = 0.07$	1.687	3.244	7.728
$\psi = 0.05$	1.683	3.244	7.718
$\psi = 0.03$	1.677	3.243	7.705
$\psi = 0.01$	1.667	3.242	7.689

Table 5: Varying capital mobility; the policy-maker's question.

In each row, the first column shows the value of ψ, a lower value corresponding to greater capital mobility. Because this is the policy-maker's question, for that value of ψ, in each row the parameters Δ and q and the initial values of a and z are re-calibrated to meet the calibration targets in table 2 and an initial debt-output ratio of 0.2519 (assuming no TFP shock); the remaining parameters also taking the values given in table 2. The second column reports the rates of structural transformation implied by the model for these parameters without a TFP shock. The third column, also for these parameters, gives the required percentage increase in consumption expenditure along the baseline path to be welfare-equivalent to a 10% shock to agricultural TFP. The fourth column reports the size of the non-agricultural TFP shock that would be required to achieve the same welfare gain. Source: authors' simulations.

the steady state, reflected in the capital-output ratios shown in panel 7b. The effect on structural transformation is shown in panel 7c: easier international borrowing accelerates structural transformation, especially early on, as would be expected.

Nonetheless, the welfare gains of the shock to capital mobility are modest, in keeping with the well-known findings of Gourinchas and Jeanne (2006). The welfare gain from easier borrowing is equivalent to just a 0.75% proportional gain in baseline consumption expenditure. Intuitively, in a Ramsey model, cheaper borrowing would only bring large welfare gains if the capital could not have been accumulated in any case, perhaps due to a strong subsistence constraint on saving. Gourinchas and Jeanne (2006) provide more rigorous intuition; for more discussion, see also Obstfeld and Taylor (2004) and Hoxha et al. (2013).

9 Conclusion

In this paper we have described a tractable two-sector, three-factor dynamic model of a small open economy, close to the models used in Roe et al. (2010). The model can be used to study structural transformation arising from sector-specific technical progress and capital accumulation. It gives rise to an asymptotic balanced growth path without the need for restrictive knife-edge assumptions, and an extension to partial international capital mobility is straightforward. We have described a solution procedure, and used the model to cast some light on development priorities.

In particular, we quantify the welfare gains from sector-specific productivity improvement, and examine how they vary across different scenarios. An advantage of an explicit welfare calculation is that we take into account foregone consumption, rather than emphasizing only aggregate growth effects. Our main finding is that, when a country is undergoing structural transformation, it matters whether an assessment of priorities is forward-looking. Although agriculture is initially the largest sector in terms of employment, we typically find that gradual gains in the level of non-agricultural productivity are more beneficial than gradual gains in agriculture. This result continues to hold even when sector-specific rates of technical progress are slow.

In our simulations, capital accumulation contributes to a fast rate of structural transformation. Assuming a higher discount rate slows down capital accumulation and the rate of transformation. This is also true of taxes on profits, reflecting the formal tax system, or perhaps corruption and other forms of institutional weakness. The model is simple enough that it could readily be extended in many directions.

10 Supplementary material

Supplementary material is on the OEP website. These are the data and replication files and the online appendix.

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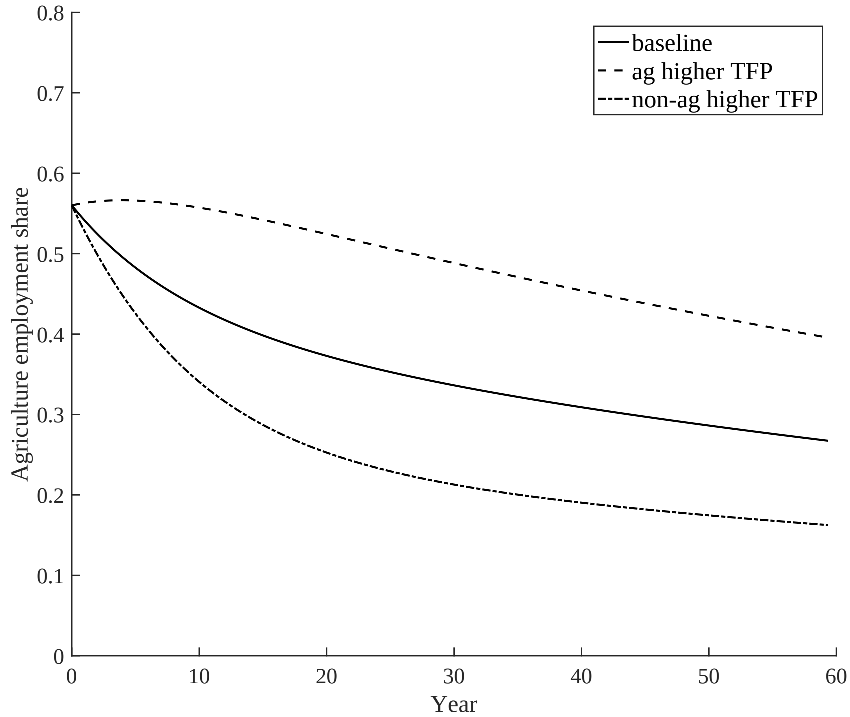
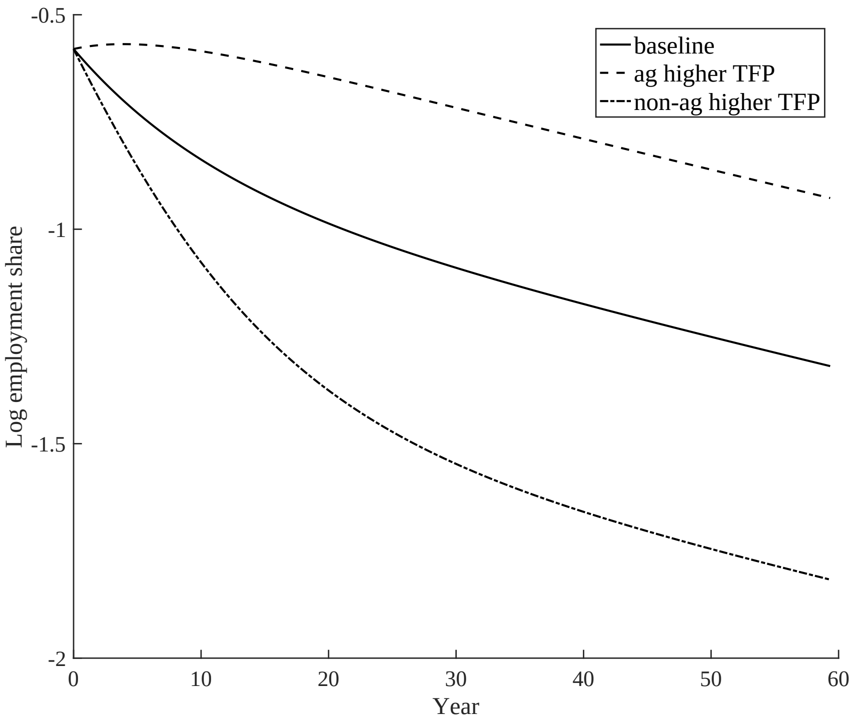
Figure 4: Agricultural employment

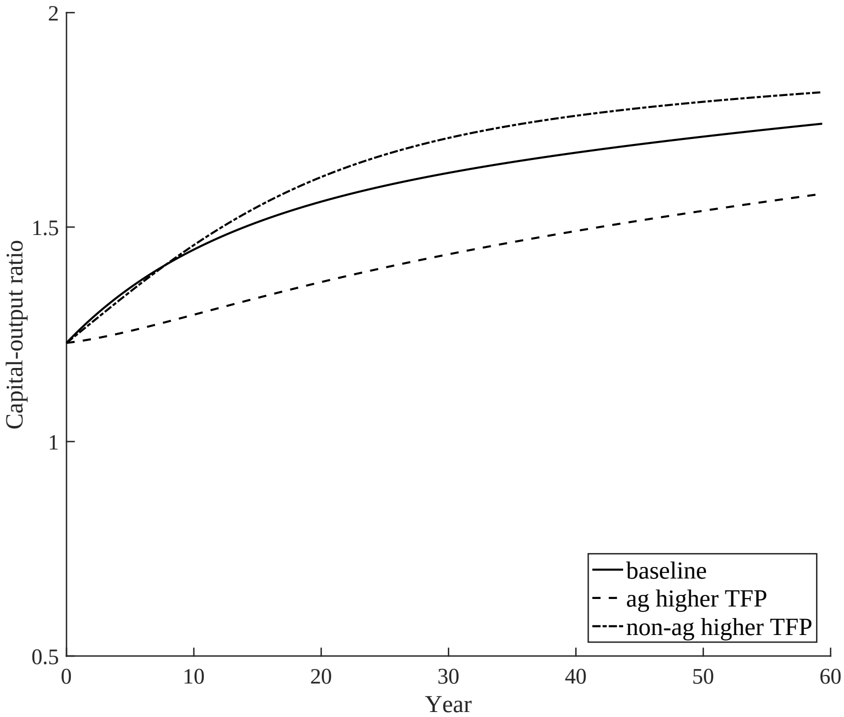


(a) Agricultural employment share

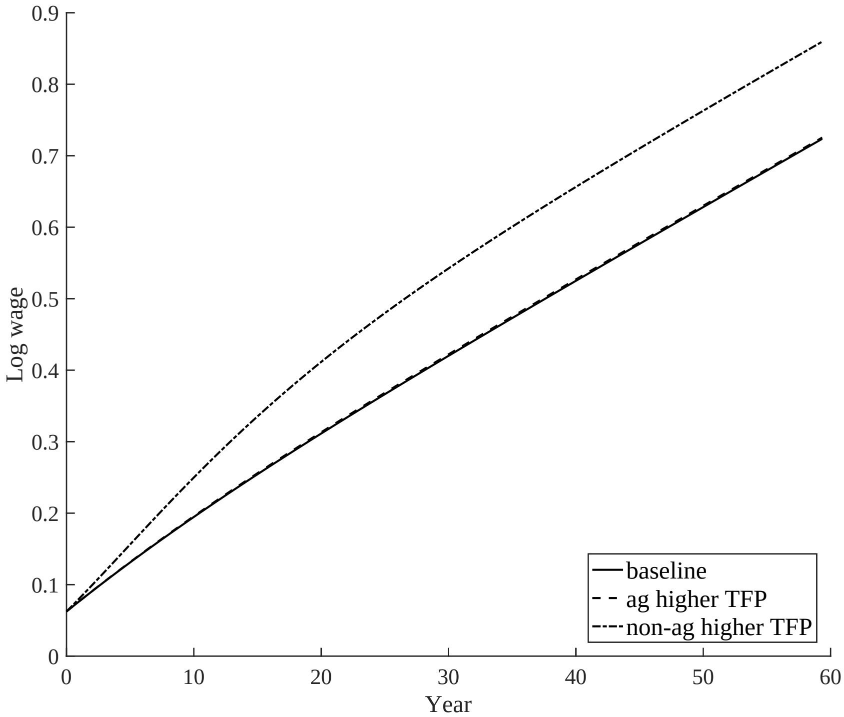


(b) Log agricultural employment share

Figure 5: Capital and wages

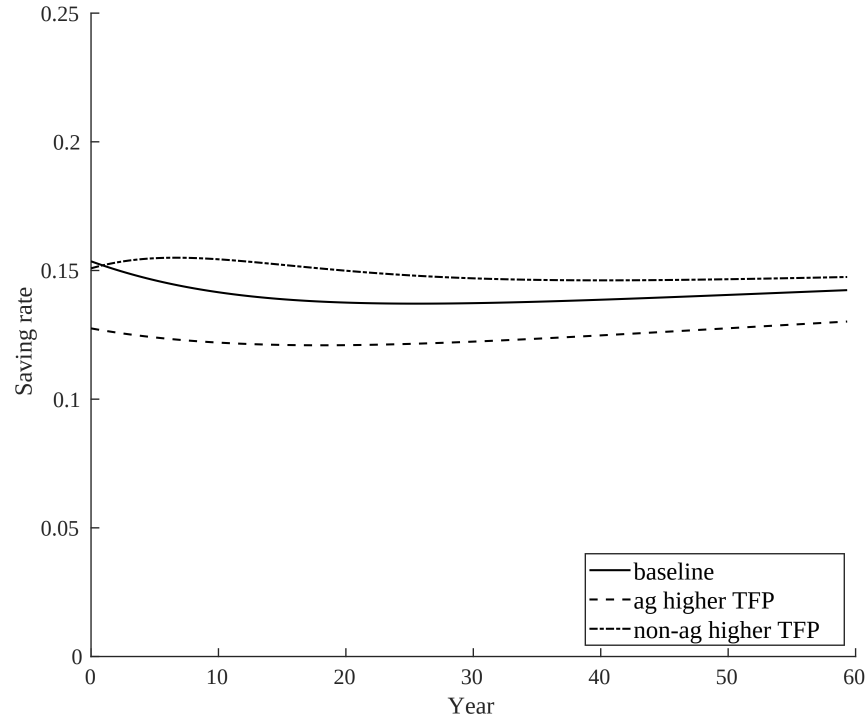


(a) Capital-output ratios

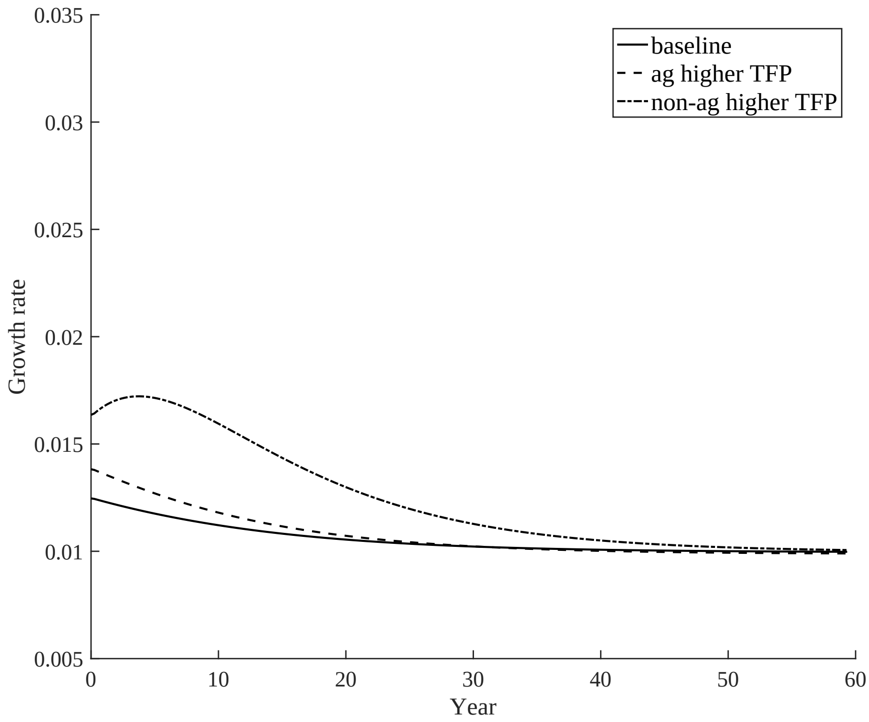


(b) Log wages

Figure 6: Saving rates and growth rates

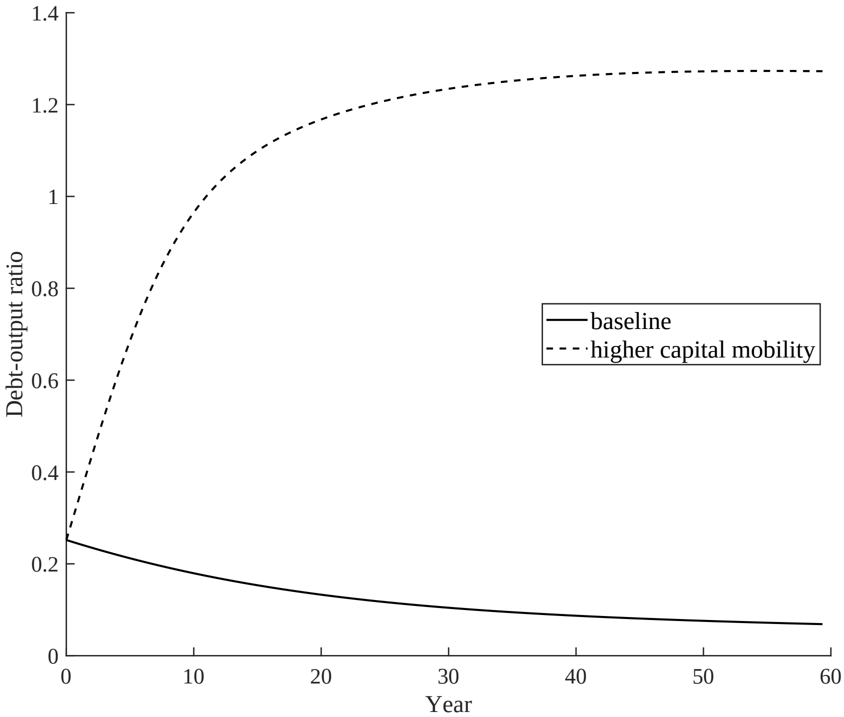


(a) Saving rates

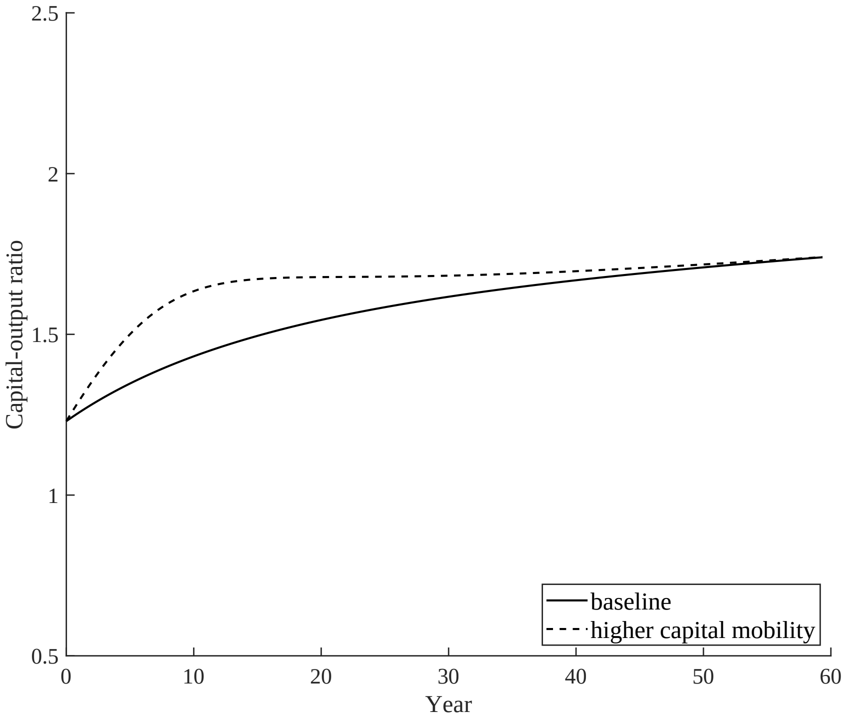


(b) Annual growth rates

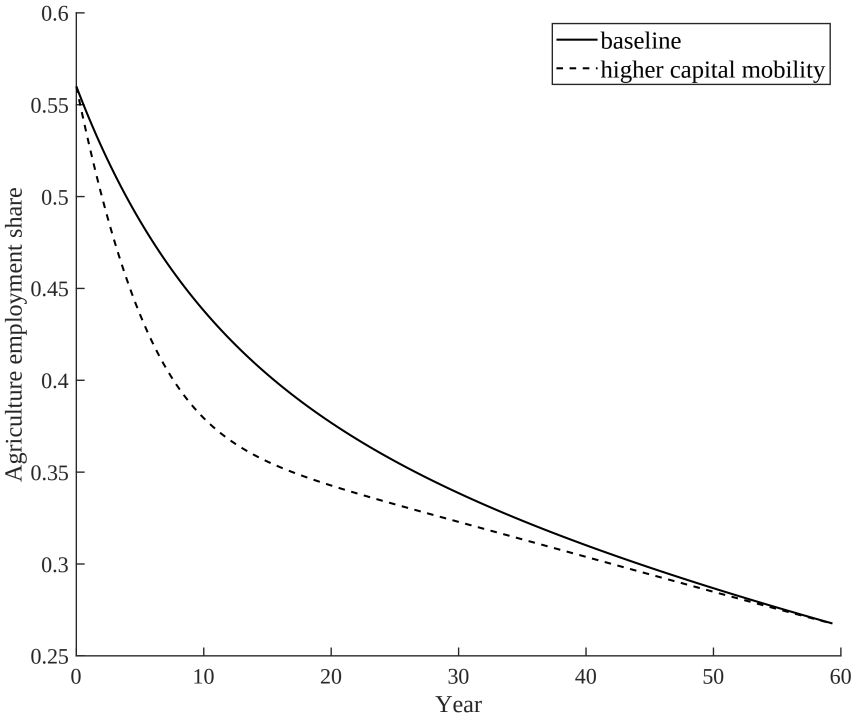
Figure 7: Capital Mobility Shock



(a) Debt-output ratios



(b) Capital-output ratios



(c) Agricultural employment share