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Natural Resource Wealth and Directed Technical Change

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Abstract

This paper analyses the effect of a resource discovery on an open economy with endogenous directed technical change. Technical progress depends on entrepreneurs who produce (or adopt) technology, and endogenously choose which sector to operate in. The static effect of a resource discovery is de-industrialization and a rise in non-resource factor incomes, as in standard trade theory. Dynamically, the "brain drain" of entrepreneurs into the resource sector may exacerbate the de-industrialization over time, but if the discovery is not sufficiently large then it leads to temporarily lower growth in non-resource factor incomes, which are lower in the long run than without the discovery. In this case non-resource owners are made worse off by the discovery. Second best trade or investment policies that direct entrepreneurs away from the resource sector may be used to raise long-run non-resource income, at a cost to GDP.

Keywords: economic growth; Dutch disease; natural resource wealth; directed technical change; distribution of income

JEL Classification: D33; F11; F43; O13; O31; O41; Q33

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1 Introduction

A large natural resource discovery transforms an economy. It becomes richer, at least in the short term. The structure of output changes both because of the new production possibilities, and as the new-found wealth raises domestic demand and alters its composition. The distribution of income changes as the benefits of the resource accrue to different sectors of the economy to varying degrees. But the exploitation of a natural resource requires technological investment, and the effects of a resource discovery on the economy over time depend on how the economy reacts to the new investment opportunities it presents. By taking into account the composition of investment, this paper analyses the dynamic impact of a resource discovery on economic structure and the distribution of income.

In particular, the contribution of this paper is to analyse the effect of a resource discovery through its impact on the direction of technical change in a multi-sector open economy. The static effects of a resource discovery, including de-industrialization or Dutch Disease, have been thoroughly investigated in the trade theory literature (see, e.g., Corden and Neary, 1982). Goderis and Malone (2011) apply Corden and Neary's (1982) model to the question of inequality between high-skill and low-skill workers. But dynamic models of resource discoveries have assumed different rates of technical change across sectors, and have not attempted to explain the pattern of technical change itself (e.g. Van Wijnbergen 1984, Neary and Wijnbergen 1985, Sachs and Warner 1995, and Torvik 2001).¹ These papers have assumed a higher rate of growth in manufacturing than in the rest of the economy, due to learning-by-doing and positive spillovers, in order to explain the Resource Curse, the proposition that natural resource-rich countries tend to grow more slowly than resource-poor countries. In particular, they assume no technical progress in the resource sector.

This paper aims to fill this gap by presenting a model of a resource-rich economy in which the inter-sectoral allocation of technical progress is endogenized as the outcome of the optimizing actions of agents. Two empirical observations underly the

¹Ngai and Pissarides (2007) also model a multi-sector economy with exogenous technical change, without a specific resource sector.

different approach I take to investment in the resource sector. First, economic historians have shown that the development of the resource sector has been as intensive in technological investments as any manufacturing sector. Thus Wright and Czelusta's (2004, p. 10) write that "the abundance of [US] American mineral resources should not be seen as merely a fortunate natural endowment. It is more appropriately understood as a form of collective learning, a return on large-scale investments in exploration, transportation, geological knowledge, and the technologies of mineral extraction, refining, and utilization". These investments, from the basic science of geology and chemistry up to the development of special materials or equipment used in the sector, are not obviously different from R&D investments in manufacturing.

Second, it is a common observation in oil-rich developing countries that national oil companies (NOCs) attract much of the best national entrepreneurial talent, in a process of "brain drain" out of the the rest of the economy. Indeed, it is a common complaint of executives in NOCs that their governments ask them to manage large public investments outside the oil sector, such as the building of schools and hospitals, because NOCs are often considered the only really competent arm of government.

This view contrasts with Sachs and Warner's (2001, p. 837) view that the movement of entrepreneurs into the resource sector "will crowd out growth-promoting entrepreneurship of all kinds." On this view entrepreneurs who are productive and growth-promoting when working in the rest of the economy suddenly become unproductive rent seekers when they move into the resource sector (also see Baumol, 1990, Gelb et al., 1988, and Murphy et al., 1991). Most of those who interact with NOCs do not recognise this characterization. It is also inconsistent with the fact that NOCs in developing countries are usually better run than most companies in the rest of the economy, or with the fact that some NOCs, such as Saudi Aramco and Brazil's Petrobras, are recognised internationally as global technology leaders in countries that are otherwise at middling levels of development. These examples demonstrate that, in at least in some cases, entrepreneurs in the resource sector are just as productive and growth-promoting as those in the rest of the economy.²

²Mehlum, Moene and Torvik (2006) and Boschini, Pettersson and Roine (2007) argue that there

The model draws on Corden and Neary (1982) and Acemoglu (2002). Corden and Neary present a range of static models of a three-sector open economy, using them to analyse the effect of a resource boom. Acemoglu (2002) presents a dynamic model of directed technical change in a two-sector closed economy.³ Both models analyse the impact of changes in factor endowments on the structure of output and relative factor returns, but they cover quite different mechanisms. Corden and Neary use traditional competitive trade theory with no endogenous technical change, while the core of Acemoglu's model is endogenous growth theory. The model I present can be thought of as an endogenous growth version of Corden and Neary, or a three-sector open-economy version of Acemoglu. Endogenizing technical change *à la* Acemoglu requires the use of explicit production and demand functions, and the price of this is to lose the generality of Corden and Neary's approach. On the other hand, explicit functions have the advantage of illuminating the role of various parameters.

The benefit of combining the approaches is to show how the static and dynamic effects interact. In the absence of factor movement towards the resource sector (as is assumed in the model here), traditional trade theory predicts that a resource discovery will raise non-resource factor incomes (e.g. wages), leading to de-industrialization or Dutch Disease. I find that the dynamic effect of a resource discovery is to exacerbate de-industrialization in the long run as technical progress accelerates in the resource sector and stalls in the manufacturing sector. However, if the resource discovery is not sufficiently large then it reduces the rate of growth of non-resource factor incomes. Thus the static and dynamic mechanisms both cause de-industrialization, but under certain circumstances they push non-resource factor incomes in opposite directions.

In analysing the impact of a resource discovery on factor incomes - or to put it another way, the difference between a resource-rich economy and a resource-poor economy - I consider the case where households own labour and capital, while some other agents, such as the government and international mining companies, own the

is a resource curse only when institutions more generally foster rent seeking activity. On this view there may be rent seeking, but it would be driven by institutional arrangements more generally rather than the resource sector per se.

³Acemoglu and Zilibotti (2001) and Acemoglu (2003a, b) analyse similar models in different contexts.

natural resource. Household primary (or market) income is thus due to wages and the return to capital only, and the impact of a resource discovery on private sector income works only through its effect on returns to these factors.

To the extent that the government redistributes resource revenues to households resource rents may add to secondary (post-fisc) household income, and to the extent that the government spends revenues on public services, they may add to household utility. However, there are two reasons to distinguish between household primary income and income or services provided by the government. First, considerable evidence suggests that some share of government resource revenues are not spent in ways that benefit the population, so a dollar per capita of resource revenues to the government is probably worth less to households than a dollar per capita of primary income. For instance, Gelb et al. (1988) and Collier and Gunning (1999) cite numerous examples of white elephant projects in which public money from resource booms has been squandered.

The second reason is that people's attitudes towards primary real income and receipts from government are different, and this difference can be politically salient. A reduction in primary real income, such as through inflation, often induces political opposition even if it is accompanied by fiscal compensation. This is clear, for instance, in countries that have tried to reduce large fuel subsidies in order to lower the fiscal burden. In 1989 Venezuela raised fuel prices, sparking mass riots that resulted in the deaths of several hundred people. Today gasoline prices in Venezuela remain under 5 US cents per litre. In 1998 Indonesia increased fuel prices, leading to violent public protests and the eventual downfall of the government.⁴

The analysis of the model is thus motivated partly by the question of when a resource discovery benefits citizens. Does it improve household real income regardless of who owns the resource and how they spend the revenues? Or is it good for households only when they get to enjoy some of the revenue directly? I find that under some circumstances a resource discovery reduces household income in the long-run, relative to not having the resource. I show that this can be prevented by trade or

⁴These examples, along with a range of issues surrounding fuel subsidies, are discussed in Bacon and Kojima (2006).

investment policies that keep entrepreneurs from moving out of manufacturing (i.e. non-resource tradables) and into the resource sector. This can increase household income in the long run, though at the cost of lower total GDP.

Section 2 presents the static model, which is a standard three-factor, three-sector competitive trade model, augmented by the inclusion of entrepreneurs who sell machines in a monopolistically-competitive market. Section 3 then endogenizes directed technical change and analyses the impact of a resource discovery over time, comparing the dynamic effects with the static effects of the previous section. Section 4 concludes.

2 The static model

I start with a static model with three factors and three intermediate sectors. The sectors are resource exports (e.g. oil or other minerals) E , import-competing domestic output (e.g. agriculture and manufacturing) M , and non-traded services S , with output Y_Z in sector Z . There are three factors of production, labour L , capital K , and a natural resource R . Labour and capital are used in sectors M and S , while the natural resource R is used in sector E . By assuming that the resource sector does not employ labour or capital I am treating it as an ‘enclave’ sector (Sachs and Warner, 1995, make the same assumption). The effect in the model is to eliminate what Corden and Neary denote the ‘resource movement’ effect, in which the booming sector draws factors of production (the ‘resources’) out of the rest of the economy. It simplifies the analysis by restricting the effect of the resource boom to its effect on the real exchange rate. But it is also quite plausible. The assumption that labour is not employed in the natural resource sector is certainly close to the truth, reflecting the fact that even very large natural resource sectors typically employ only a tiny share of the labour force. With capital K interpreted as domestic capital, it is also reasonable to assume that domestic capital owners cannot invest in the resource sector. One could also interpret K as any other factor of production not used in significant proportions by the resource sector.

Each sector Z also uses technology in the form of machines $x_Z(i)$ that embody

technical progress. These machines are produced from the final good and thus comprise a reproducible, rather than scarce, type of capital. In each sector Z the level of technology is A_Z , where the range of available machines $x_Z(i)$ in each sector is defined by $i \in [0, A_Z]$. Factor and goods markets are competitive and take the A_Z 's as given, but later I will introduce a monopolistically-competitive market for technology where the A_Z 's will be endogenized.

The production functions are

$$Y_E = \frac{R^{\alpha+\beta}}{1-\alpha-\beta} \int_0^{A_E} x_E(i)^{1-\alpha-\beta} di \quad (1)$$

$$Y_M = \frac{L_M^\alpha K_M^\beta}{1-\alpha-\beta} \int_0^{A_M} x_M(i)^{1-\alpha-\beta} di \quad (2)$$

$$Y_S = \frac{L_S^\beta K_S^\alpha}{1-\alpha-\beta} \int_0^{A_S} x_S(i)^{1-\alpha-\beta} di \quad (3)$$

while full employment implies that

$$L_M + L_S = L$$

$$K_M + K_S = K.$$

Output of the final good Y is a CES function of the nontradable good S and an aggregated tradable good T . The natural resource export is traded for imports, which have the same exogenous price p_T as domestic tradables. Units of the export are chosen so that the price of exports is also p_T , and I set $p_T = 1$ as the numeraire. Thus

$$Y = \left[\gamma Y_S^{\frac{\varepsilon-1}{\varepsilon}} + (1-\gamma) T^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} \quad (4)$$

where ε is the elasticity of substitution between tradables and non-tradables, and

$$T = Y_M + Y_E. \quad (5)$$

With p_Y the price of the final good, we have⁵

$$p_Y = [\gamma^\varepsilon p_S^{1-\varepsilon} + (1-\gamma)^\varepsilon]^{\frac{1}{1-\varepsilon}}. \quad (6)$$

Product markets are competitive so from (4) demand for Y_S and Y_M implies that the price of Y_S in terms of the price of Y_M is

$$p_S = \frac{\gamma}{(1-\gamma)} \left(\frac{T}{Y_S} \right)^{1/\varepsilon}, \quad (7)$$

which is also the real exchange rate.

Factor returns are competitively determined and labour and capital are mobile between sectors M and S . With a wage of w , return to capital r , and a return ('rent') to the natural resource of v , factor returns are determined by the factor demand equations

$$w = \frac{1}{p_Y} \frac{\alpha}{1-\alpha-\beta} L_M^{\alpha-1} K_M^\beta \int_0^{A_M} x_M(i)^{1-\alpha-\beta} di \quad (8)$$

$$= \frac{p_S}{p_Y} \frac{\beta}{1-\alpha-\beta} L_S^{\beta-1} K_S^\alpha \int_0^{A_S} x_S(i)^{1-\alpha-\beta} di \quad (9)$$

$$r = \frac{1}{p_Y} \frac{\beta}{1-\alpha-\beta} L_M^\alpha K_M^{\beta-1} \int_0^{A_M} x_M(i)^{1-\alpha-\beta} di \quad (10)$$

$$= \frac{p_S}{p_Y} \frac{\alpha}{1-\alpha-\beta} L_S^\beta K_S^{\alpha-1} \int_0^{A_S} x_S(i)^{1-\alpha-\beta} di \quad (11)$$

$$v = \frac{1}{p_Y} \frac{\alpha+\beta}{1-\alpha-\beta} R^{\alpha+\beta-1} \int_0^{A_E} x_E(i)^{1-\alpha-\beta} di. \quad (12)$$

Note that r is the return to non-reproducible capital, rather than the interest rate.

Final goods producers buy machines in order to maximize profits, given factor returns and the price χ_Z of each machine in sector Z . The FOCs for this profit

⁵This follows from the fact that the price p_Y is consistent with minimizing the cost of achieving a given Y . Then p_Y satisfies the FOCs for the minimization, e.g. $p_Y \frac{\partial Y}{\partial Y_S} = p_S$. Thus $1 = p_Y = p_S \div \frac{\partial Y}{\partial Y_S} = p_T \div \frac{\partial Y}{\partial T}$.

maximization produce machine demands

$$\begin{aligned} x_E(i) &= \left(\frac{1}{\chi(i)_E} \right)^{\frac{1}{\alpha+\beta}} R \\ x_M(i) &= \left(\frac{1}{\chi(i)_M} L_M^\alpha K_M^\beta \right)^{\frac{1}{\alpha+\beta}} \\ x_S(i) &= \left(\frac{p_S}{\chi(i)_S} L_S^\beta K_S^\alpha \right)^{\frac{1}{\alpha+\beta}}. \end{aligned}$$

The price $\chi(i)$ of machines is chosen by the entrepreneur. Assume it costs ψp_Y to build a machine in any sector. Each entrepreneur sells machines at the monopoly price by maximizing profit subject to demand:

$$\max_{x_Z} x_Z (\chi_Z - \psi p_Y). \quad (13)$$

This implies

$$\chi_E = \chi_M = \chi_S = \frac{\psi p_Y}{(1 - \alpha - \beta)}.$$

I follow Acemoglu (2002) in assuming that $\psi = 1 - \alpha - \beta$. This loses some generality, but is harmless as long as we are not interested in what happens if ψ changes. Then in all sectors and for all i the price of machines is equal to the price of the final good, with $\chi_E = \chi_M = \chi_S = p_Y$. Hence machine demand is

$$x_E = \left(\frac{1}{p_Y} \right)^{\frac{1}{\alpha+\beta}} R \quad (14)$$

$$x_M = \left(\frac{1}{p_Y} L_M^\alpha K_M^\beta \right)^{\frac{1}{\alpha+\beta}} \quad (15)$$

$$x_S = \left(\frac{p_S}{p_Y} L_S^\beta K_S^\alpha \right)^{\frac{1}{\alpha+\beta}}. \quad (16)$$

I assume that machines fully depreciate each period. Substituting (14)-(16) into

(1)-(3), the supply of output is

$$Y_E = \frac{A_E}{1 - \alpha - \beta} p_Y^{\frac{\alpha + \beta - 1}{\alpha + \beta}} R \quad (17)$$

$$Y_M = \frac{A_M}{1 - \alpha - \beta} p_Y^{\frac{\alpha + \beta - 1}{\alpha + \beta}} \left(L_M^\alpha K_M^\beta \right)^{\frac{1}{\alpha + \beta}} \quad (18)$$

$$Y_S = \frac{A_S}{1 - \alpha - \beta} \left(\frac{p_S}{p_Y} \right)^{\frac{1 - \alpha - \beta}{\alpha + \beta}} \left(L_S^\beta K_S^\alpha \right)^{\frac{1}{\alpha + \beta}} \quad (19)$$

Substituting (14)-(16) into (8)-(12), factor returns are

$$w = \frac{\alpha}{1 - \alpha - \beta} A_M p_Y^{-\frac{1}{\alpha + \beta}} \left(\frac{K_M}{L_M} \right)^{\frac{\beta}{\alpha + \beta}} = \frac{\beta}{1 - \alpha - \beta} A_S \left(\frac{p_S}{p_Y} \right)^{\frac{1}{\alpha + \beta}} \left(\frac{K_S}{L_S} \right)^{\frac{\alpha}{\alpha + \beta}} \quad (20)$$

$$r = \frac{\beta}{1 - \alpha - \beta} A_M p_Y^{-\frac{1}{\alpha + \beta}} \left(\frac{L_M}{K_M} \right)^{\frac{\alpha}{\alpha + \beta}} = \frac{\alpha}{1 - \alpha - \beta} A_S \left(\frac{p_S}{p_Y} \right)^{\frac{1}{\alpha + \beta}} \left(\frac{L_S}{K_S} \right)^{\frac{\beta}{\alpha + \beta}} \quad (21)$$

$$v = \frac{\alpha + \beta}{1 - \alpha - \beta} A_E p_Y^{-\frac{1}{\alpha + \beta}}. \quad (22)$$

The static model is now complete and I consider comparative statics, asking what happens if a country discovers natural resources. That is, what is the effect of a rise in R ? I first show that it leads to a rise in the real exchange rate p_S and then consider the impact on output and factor returns.

2.1 The static impact of a resource discovery

A rise in R increases income and hence aggregate demand, but has no impact on the supply function of S because the natural resource sector does not share any scarce factors of production with the rest of the economy. This implies that the real exchange rate p_S must rise (see the Appendix for a formal proof).

This rise in the real exchange rate affects both the structure of output and relative factor returns. First considering the structure of output, sectors M and S comprise a two-sector, two-factor Heckscher-Ohlin model augmented by the inclusion of machines. Standard results apply so the rise in p_S induces a rise in Y_S and a decline in Y_M as both labour and capital are drawn away from M and into S . Thus there is de-industrialization, or Dutch disease.

The existence of machines in the model exacerbates this effect: the rise in p_S

implies that the price of machines p_Y rises relative to the price of tradables and falls relative to p_S (from equation 6). Hence through the terms in p_Y and p_S in the production functions (18) and (19) fewer machines are employed in Y_M and more in Y_S so the use of machines amplifies the impact on output in both sectors. This is similar to Corden and Neary's (1982) 'resource movement effect', although the 'resource' in question is reproducible machines rather than a scarce factor.

Turning to factor returns, the Stolper-Samuelson theorem tells us that the return to the factor used intensively by S rises by more than p_S , and thus enjoys a real increase, while the return to the other factor falls nominally and therefore also in real terms.⁶

As discussed earlier, however, the total aggregate of non-resource real income is also of interest as the primary (pre-fisc) income of households. So consider the non-resource economy as households that own labour and capital and produce Y_M and Y_S , and assume that the government or a small number of private agents owns the natural resource. Then $wL + rK$ accrues to households while vR accrues to the resource owner. What is the effect of a resource discovery on the real primary income of households?

We can consider the non-resource economy, i.e. households, and the resource sector as two economies trading with one another, with households 'exporting' Y_S to the resource sector and buying imports from the rest of the world. Then the rise in the real exchange rate represents an improvement in the terms of trade for households, and therefore a rise in utility. Thus the resource discovery increases the real income of the non-resource economy, even if the non-resource economy receives none of the resource revenues. (A formal proof is in the Appendix).

This discussion demonstrates that standard results in static trade theory hold in the model: a resource boom implies a rise in the real exchange rate, deindustrialization, and a rise in non-resource factor income.

⁶The classic analysis of Jones (1965) applies. The existence of machines in production implies a minor change in the price-cost equations, which does not affect the directions of change. With a_{ij} the unit requirement of factor i in sector j , labour and capital costs are related to prices as

$$wa_{Lj} + ra_{Kj} = (\alpha + \beta) p_j.$$

The remainder, $(1 - \alpha - \beta) p_j$, accrues to entrepreneurs.

3 Endogenizing directed technical change

I now turn to the dynamic analysis to see how these outcomes are affected by directed technical change. I assume that technology adoption in each sector Z is proportional to the number of entrepreneurs N_Z in the sector, while the total exogenous stock of entrepreneurs is N . For steady-state growth to be possible requires that technical change also be proportional to the level of technology in the sector, so current entrepreneurs stand on the shoulders of their predecessors.⁷ Thus

$$\begin{aligned}\dot{A}_E &= \eta_E A_E N_E \\ \dot{A}_M &= \eta_M A_M N_M \\ \dot{A}_S &= \eta_S A_S N_S \\ N_E + N_M + N_S &= N\end{aligned}$$

where η_Z indexes the ease of producing new designs in sector Z , so one entrepreneur in sector Z generates $\eta_Z A_Z$ new designs of machine.

The entrepreneur's maximization in equation (13) implies profits π per machine in the different sectors of

$$\begin{aligned}\pi_E &= (\alpha + \beta) \left(\frac{1}{p_Y} \right)^{\frac{1}{\alpha + \beta}} R \\ \pi_M &= (\alpha + \beta) \left(\frac{1}{p_Y} \right)^{\frac{1}{\alpha + \beta}} \left(L_M^\alpha K_M^\beta \right)^{\frac{1}{\alpha + \beta}} \\ \pi_S &= (\alpha + \beta) \left(\frac{p_S}{p_Y} L_S^\beta K_S^\alpha \right)^{\frac{1}{\alpha + \beta}}.\end{aligned}$$

Entrepreneurs care about the net present value of their machine designs V_Z where

$$V_Z \equiv \sum_{t=0}^{\infty} \left(\frac{1}{1+i} \right)^t \pi_Z \quad (23)$$

where i is the (exogenous) interest rate. Later I show that in the long run the

⁷The implication is that, as in Romer (1990, p. S84), "unbounded growth is more like an assumption than a result of the model." The point, however, is to analyse the impact of resource wealth on the direction, and not the aggregate rate, of technical change.

economy will grow at rate $N \frac{\eta_S \eta_Z}{\eta_S + \eta_Z}$ for $Z = E$ or M , so to ensure that $V_Z < \infty$ I assume that $i > N \frac{\eta_S \eta_Z}{\eta_S + \eta_Z}$. Following standard dynamic programming we also have

$$V_Z = \frac{\pi_Z + \dot{V}_Z}{i} \quad (24)$$

where \dot{V}_Z is the time derivative of V_Z .

For technology adoption to take place in all sectors requires that the value of being an entrepreneur be equal in all sectors, i.e. $\eta_E A_E V_E = \eta_M A_M V_M = \eta_S A_S V_S$. Observe that from (17)-(19), profit per machine π_Z is proportional to $\frac{p_Z Y_Z}{A_Z}$. Then noting that in steady state $\dot{V}_Z = 0$, from (24) we have the three-sector equilibrium technology market clearing condition, denoted TMC,

$$\eta_E Y_E = \eta_M Y_M = \eta_S p_S Y_S. \quad (25)$$

Equilibrium will be possible between just two sectors, so let $\text{TMC}(Q, Z)$ be the condition that there are entrepreneurs in the two sectors Q and Z , and not in the third sector W . That is, in equilibrium $\text{TMC}(Q, Z)$ is

$$\eta_Q p_Q Y_Q = \eta_Z p_Z Y_Z > \eta_W p_W Y_W \quad (26)$$

where $p_E = p_M = 1$.

3.1 Equilibrium and balanced growth

I now describe equilibrium under constant factor endowments; in the next section I describe the impact of a resource discovery, or increase in R . Define a *balanced growth path* (BGP) as a stable equilibrium in which relative prices and relative output are constant. For relative prices to be constant requires that Y_S grow at the same rate as $T = Y_E + Y_M$, so a BGP could have equal rates of growth in all three sectors, or equal rates of growth in Y_S and one of the traded sectors, while output in the other traded sector is zero.

The following proposition is proved in the Appendix.

Proposition 1 (*Dynamic equilibrium*)

(i) *There is no stable dynamic equilibrium with both A_E and A_M growing.*

(ii) *Let $\varepsilon < 1$. There are two stable dynamic equilibria if $R > 0$. (a) A "resource-rich BGP" with $TMC(S, E)$ where Y_S and Y_E grow at some constant rate g^{SE} , while $Y_M = 0$; (b) asymptoting towards a "resource-poor BGP" with $TMC(S, M)$ where Y_S and Y_M grow at some constant rate g^{SM} , while Y_E asymptotes to zero as a share of GDP. If $R = 0$ then $Y_E = 0$ on the resource-poor BGP.*

To sum up, if $\varepsilon < 1$ then in the long run the economy can be in a BGP with growth in S and E , or asymptoting to a BGP with growth in S and M . What is the growth rate on the BGP? On the BGP $\dot{A}_S/A_S = \dot{A}_Z/A_Z$ (for $Z = E$ or M) so $\eta_S N_S = \eta_Z N_Z$, and the number of entrepreneurs in each of the two growing sectors will be

$$N_S = N \frac{\eta_Z}{\eta_Z + \eta_S} \quad N_Z = N \frac{\eta_S}{\eta_Z + \eta_S}.$$

The growth rate in each of the two growing sectors will therefore be

$$g^{SZ} = N \frac{\eta_S \eta_Z}{\eta_S + \eta_Z}. \quad (27)$$

On the BGP the third sector is equal to zero as a share of GDP, so g^{SZ} is also the growth rate of the aggregate economy. Thus the earlier assumption on the interest rate i implies that $i > g^{SZ}$, which guarantees that $V_Q < \infty$ for all Q .

Equation (27) can imply a "Resource Curse" if we make the assumption that technical progress in the resource sector is slower per entrepreneur than in the non-resource tradable sector. This assumption would mean that $\eta_E < \eta_M$, from which it would follow that $g^{SE} < g^{SM}$. Then aggregate growth in the resource-rich BGP would be lower than in the resource-poor BGP. The model therefore embeds this aspect of the models of van Wijnbergen (1984), Neary and Wijnbergen (1985), and Sachs and Warner (1995), all of which make such an assumption.

We can also calculate the relative output of the two growing sectors on the BGP. The condition $TMC(S, Z)$ immediately tells us that the relative value of output at

current prices is

$$\frac{p_S Y_S}{Y_Z} = \frac{\eta_Z}{\eta_S}.$$

Thus a sector's share of GDP is inversely proportional to the relative productivity η of entrepreneurs in that sector: the faster the rate of growth per entrepreneur in a sector, the smaller the sector is as a share of GDP. However, in terms of absolute output, noting that $Y_Z = T$ on the BGP, we can use equation (7) to substitute for p_S to find that

$$\frac{Y_S}{Y_Z} = \left(\frac{\gamma \eta_S}{(1 - \gamma) \eta_Z} \right)^{\frac{\varepsilon}{1 - \varepsilon}}.$$

Thus output in a sector, in contrast to the *value* of output, is *positively* related to the productivity of entrepreneurs in that sector (assuming, as ever, that $\varepsilon < 1$).

We have assumed that the elasticity of substitution between tradables and non-tradables, ε , is less than unity. As also found by Torvik (2001), this is necessary for stable multi-sector growth. What do we know empirically about this quantity? A small number of empirical studies have estimated it for a range of countries. A series of studies by the Inter-American Development Bank estimate it for four Latin American countries: Argentina, Bolivia, Costa Rica and Uruguay (respectively González Rozada et al., 2004, Barja Daza et al., 2005, Arce and Robles, 2004, and Lorenzo et al., 2005). For Argentina, Bolivia and Uruguay, all estimates are less than one, lying between 0.40 and 0.75. In Costa Rica it is found to be substantially below one in annual data (in the interval (0.22, 0.28)), but greater than one in quarterly data (in the interval (1.46, 2.14)). Cashin and McDermott (2003) estimate it for the five developed countries Australia, Canada, New Zealand, UK and US. It is significantly above one at the 5% level for Australia and Canada, and at the 10% level for the UK. The estimate for the US is not statistically different from zero owing to large standard errors, and the estimate for New Zealand is significantly below one and above zero. Thus within this small group of studies most estimates for developing countries put ε below one, but several estimates for developed countries put it above one. If one considers tradables as dominated by agriculture and manufactures, while non-tradables include housing, transport, and haircuts, it would appear intuitive that the two sectors have a low degree of substitutability, but the data do

not appear to be consistent across countries on the question.

3.2 The dynamic impact of a resource discovery

With the above results we can now analyse the dynamic impact of a resource discovery. For the following I assume that $\varepsilon < 1$. I consider what happens when a resource-poor economy on a BGP with $TMC(S, M)$ discovers a stock of natural resources R .

Proposition 2 *If an economy on a resource-poor BGP, with $TMC(S, M)$, discovers a large enough stock of natural resources R then the economy will end up on a resource-rich BGP with $TMC(S, E)$ and $Y_M = 0$.*

There are two cases to distinguish, depending on the size of the discovery R .

In the first case the discovery is large enough that Y_M is immediately reduced to zero. Let R^* be the smallest such discovery. With $T = Y_E$ and $\varepsilon < 1$, $TMC(S, E)$ is stable and from Proposition 1 (ii) the economy will move into the resource-rich BGP.

Second, if $R < R^*$ then Y_M will not fall to zero immediately. With $\varepsilon < 1$, S is always stable with respect to $T = Y_E + Y_M$, so the value of output, and hence profitability, in at least one of E and M will converge towards that in S . Since the relative profitability of sector E to M is rising in R , there will be some R^{**} large enough that the economy reaches $TMC(S, E)$ before it reaches $TMC(S, M)$, and moves into the resource-rich BGP. If R is too small then the economy may end up asymptoting back towards a resource-poor BGP.

It remains to show that there is such a second case that results in the economy moving into the resource-rich BGP, i.e. that there is an $R^{**} < R^*$. I prove existence by providing an example. Figure 1 presents a simulation of the model. In order to make the simulation tractable I have to assume a high discount rate for entrepreneurs, so they move into whichever sector has the highest per-period profits.⁸ I

⁸Since per-period profits leapfrog one another, modeling fully forward-looking entrepreneurs would require simulating all future possible paths at every point, which is not feasible.

assume that $\eta_E = \eta_M = \eta_S = 1$ so technical progress per entrepreneur is equally rapid in all sectors.⁹

The resource discovery is made in period 20. Just after the discovery $\eta_M Y_M < \eta_E Y_E < \eta_S p_S Y_S$, so all entrepreneurs move into sector S . p_S is therefore declining and both Y_E and Y_M are rising. Counterintuitively, therefore, some of the decline in Y_M is temporarily reversed. This lasts until period 44, at which point Y_E has grown enough that $\eta_E Y_E = \eta_S p_S Y_S$. $\eta_E Y_E$ rises above $\eta_S p_S Y_S$ so all entrepreneurs move into sector E ,¹⁰ and from this point on Y_M declines, reaching zero in period 58. Then, since $\text{TMC}(S, E)$ is stable when $Y_M = 0$ (Proposition 1), $p_S Y_S$ rises relative to Y_E and the economy lands on the resource-rich BGP from period 74 onwards.

3.2.1 The dynamic effect on factor incomes

What is the impact of the resource discovery on the path of real incomes? With entrepreneurs moving into the resource sector the rise in the productivity of natural resources A_E will obviously raise the rents paid to resource owners. I now consider the effect on the real income of the non-resource sector, or households.

First observe that on a BGP household real income is rising at the same rate as GDP. After a resource discovery, we have already seen that the static effect is to raise household real income by raising the real exchange rate. Dynamically, growth in any sector will continue to raise household income: sectors S or M are owned by households and hence growth in either of them will increase household income, while growth in sector E will be equivalent to further discoveries of the natural resource, which will also increase household income.

Household incomes thus rise unambiguously in every period after the resource discovery. However, they would also have continued to rise in the absence of the discovery. I now ask the question: does the resource discovery make households better or worse off in the long run?

First define $GDP = Y_E + Y_M + p_S Y_S$, and note that total factor income is equal

⁹The simulation further assumes the following parameter values: $\alpha = 0.4$; $\beta = 0.3$; $\gamma = 0.3$; $N = 0.04$. Thus in $\text{TMC}(E)$, A_E grows at 4 percent, and in $\text{TMC}(S, Z)$, A_S and A_Z both grow at 2 percent. I set $\varepsilon = 0.6$, which is within the range of estimates referred to earlier.

¹⁰At this point $\text{TMC}(S, E)$ is unstable because Y_M is relatively large, so proposition 1 (ii) does not apply.

to $(\alpha + \beta) GDP$, while $(1 - \alpha - \beta) GDP$ accrues to entrepreneurs. Then $(\alpha + \beta) Y_E$ accrues to resource owners, while household income is

$$HHY = (\alpha + \beta) (Y_M + p_S Y_S).$$

Suppose the resource discovery occurs at time 0, and at time t the economy is on the new resource-rich BGP with $Y_M = 0$ and $TMC(S, E)$. We compare household income at time t under this scenario with a counterfactual in which there was no resource discovery. Let X^D be variable X with the discovery and X^N be the counterfactual variable in the absence of the discovery. In the resource-rich BGP after the discovery, with $TMC(S, E)$ and $Y_M = 0$, household income is equal to $(\alpha + \beta) p_S Y_S$. Thus from $TMC(S, E)$ and the fact that now $GDP = Y_E + p_S Y_S$, it follows that

$$HHY^D = (\alpha + \beta) p_S^D Y_S^D = \frac{\eta_E}{\eta_E + \eta_S} (\alpha + \beta) GDP^D. \quad (28)$$

Note that, conditional on the discovery being large enough to satisfy Proposition (2), the share of GDP owned by households is independent of the size of the discovery, although the size of GDP is not.

In the absence of the discovery, the economy remains on a BGP with $TMC(S, M)$ and $Y_E = 0$ so households own all factor income. Thus

$$HHY^N = (\alpha + \beta) GDP^N. \quad (29)$$

Then (28) and (29) imply the following.

Proposition 3 *Household income on the post-discovery BGP at time t is higher than household income would have been at time t in the absence of the discovery, i.e., $HHY_t^D > HHY_t^N$, if and only if*

$$GDP_t^D > \frac{\eta_E + \eta_S}{\eta_E} GDP_t^N. \quad (30)$$

GDP is larger after the discovery but households own a smaller share of it, and

(30) indicates the factor by which the resource discovery has to raise GDP in order for households to be better off at time t . For instance, if all the η 's are equal, then the resource discovery has to more than double GDP in order to make households better off in the long run; if it less than doubles GDP then household incomes are lower in the long run. Figure 2 simulates three cases using the same parameters as above: no resource discovery, the moderate resource discovery simulated above, and a large discovery. GDP is higher with any discovery than without, but household income (HHY in the figure) is lower under the moderate discovery than with no discovery. The large discovery is large enough that the increase in GDP more than compensates for the fact that households enjoy only half of it on the BGP.

3.2.2 Technical change and incomes policy

A resource discovery necessarily increases GDP, but we have just seen that it may lower non-resource incomes over time. This implies that policy intervention may be desirable if the distribution of income is a concern. Import tariffs or export taxes that raise the profitability of non-resource tradables M could keep entrepreneurs in that sector and out of the resource sector. Equally, the government could subsidize technical investments in the two non-resource sectors or tax them in the resource sector. Such policies may be second-best, but I described in the introduction several reasons why the first-best policy of effective expenditure or direct distribution of government revenues may not be feasible. The policy need only be temporary because with the implied growth in the non-resource economy the resource sector will eventually be small enough as a share of GDP that it will no longer attract entrepreneurs in any case.

I therefore re-simulate the model with the moderate discovery as above under the assumption that, through some combination of policies, the government induces entrepreneurs to stay in the manufacturing and services sectors, as before the discovery. Thus both A_M and A_S continue to grow at their pre-discovery rates. The result is illustrated in figure 3. The first panel of the figure shows sectoral output. Both Y_M and Y_S continue to grow because of their respective entrepreneurs. But

since Y_E is not growing, total tradables $T = Y_E + Y_M$ grows less rapidly than Y_S . This leads to p_S declining, which induces Y_M to grow more rapidly than Y_S . In the long run, as Y_E tends to zero as a share of GDP, the economy asymptotes back to a resource-poor BGP.

The second and third panels of figure 3 show GDP and household income HHY under the three scenarios of no discovery, the moderate discovery, and the moderate discovery with the policy just described. We saw earlier that the moderate discovery increases GDP but reduces HHY relative to no discovery both in the short and long run. Figure 3 shows that the moderate discovery accompanied by the policy leads to HHY being almost exactly the same as with no discovery - in fact it is very slightly larger, as implied by the earlier static result that a resource discovery increases HHY . At the same time, the policy reduces GDP relative to no policy. The absolute gain in GDP caused by the initial discovery is retained in the long run; in the figure it appears to shrink because log values are plotted. What is sacrificed is the long-run proportional, as opposed to absolute, gain offered by the resource discovery. Thus given the moderate resource discovery, this policy raises household income, but at a cost to GDP. A government concerned with income distribution would have to compare this cost with the cost associated with alternative forms of redistribution.

4 Conclusion

The extraction and processing of natural resources is one of the most technologically advanced sectors in the global economy. In resource-rich developing countries it also offers entrepreneurial individuals better opportunities than are available in other sectors of the economy. In contrast to existing discussions of entrepreneurs in the natural resource sector, this paper suggested that these individuals may be just as productive in the resource sector as in other parts of the economy.

However, by interpreting entrepreneurs as drivers of technical progress the model showed that a resource discovery may bring a halt to technical progress in the non-resource economy by attracting the limited stock of entrepreneurs into the resource

sector in a process of "brain-drain". In this equilibrium there is growth in both the resource sector and the non-traded sector, but manufacturing declines to zero. Thus in the long run the dynamic effect of the resource discovery is to exacerbate the static de-industrialization found in static trade theory models.

In analysing factor returns I assumed that households, or the private sector, own labour and capital, while resource revenues accrue to the government, foreigners, or other non-household actor. I then considered the impact of a resource discovery on household primary income. As in standard trade theoretic models, the static effect of the resource discovery is to raise the real exchange rate and thereby raise household real incomes. However, if the resource discovery is not sufficiently large then the growth in household incomes after the resource discovery will be lower than it would have been absent the discovery, owing to the diversion of entrepreneurs out of manufacturing. Such a discovery will therefore lead to lower household incomes, overturning the conclusion of static models of resource discoveries. Trade or investment policy that keeps entrepreneurs in the non-resource sectors after a resource discovery can therefore be used to prevent the negative impact on household income, although this will be at the cost of lower GDP.

The model therefore illustrates that the dynamic impact of a resource discovery may be significantly different from its static impact. Even if entrepreneurs are productive in their chosen sector, their migration into the resource sector will have distributional implications. Households in resource-rich economies may find their primary incomes reduced, making the question of who receives resource revenues, and how they are spent, all the more important.

5 Mathematical Appendix

5.1 The static impact of a resource discovery

Here I show that a rise in R increases the real exchange rate p_S/p_T . I use duality theory, following Neary (1988). Let the price of tradables p_T be fixed as the numeraire. Let e be the expenditure function and r the revenue function, or GDP. The *trade expenditure function* is the excess of home expenditure e over income from home production r for the whole economy, i.e. the current account deficit, which will be zero by assumption for the whole economy. The only varying price is p_S so with representative utility u , factor endowments as above, and assuming current account balance, we have

$$E(p_S, u, R) = e(p_S, u) - r(p_S, R) = 0 \quad (31)$$

where I suppress other variables that are kept constant (p_T in both e and r , preference parameters in e , and production parameters and L and K in r).

Let V_p be the partial derivative of variable V with respect to p_S . Thus E_p is the excess demand for the non-traded good, and

$$E_p = e_p - r_p$$

where duality theory informs us that $e_p(p_S, u)$ is the utility-compensated or Hicksian demand function for Y_S , and $r_p(p_S)$ the supply function for Y_S . Thus e_{pp} is negative and r_{pp} is positive and we define $\tau \equiv -E_{pp} = r_{pp} - e_{pp}$, which is positive.

Market clearing implies that supply and demand for the non-traded S are equal, so

$$E_p(p_S, u, R) = 0. \quad (32)$$

Totally differentiate (31), using (32) and choosing units so that the price of one util, E_u , is equal to 1, to obtain

$$du = -E_R dR. \quad (33)$$

Now totally differentiating (32) and using (33) produces

$$dp_S = \tau^{-1}dR(E_{pR} - E_R E_{pu}). \quad (34)$$

We know that $r_{pu} = 0$ because r is not a function of u ; $e_R = e_{pR} = 0$ because e is not a function of R ; and $r_{pR} = 0$ because r_p , the supply of Y_S , is also not a function of R . Thus

$$\begin{aligned} E_{pR} - E_R E_{pu} &= e_{pR} - r_{pR} - (e_R - r_R)(e_{pu} - r_{pu}) \\ &= r_R e_{pu} > 0 \end{aligned}$$

so

$$dp_S = \Lambda dR$$

where $\Lambda = \tau^{-1}r_R e_{pu} > 0$. That is, a rise in R induces a rise in p_S and thus a rise in the real exchange rate p_S/p_T .

I now show that the rise in R induces a rise in utility, or real income, for the non-resource economy. I consider the non-resource sector, i.e. households, as a separate economy, ‘exporting’ Y_S to the resource sector. I thus take E^H to be the trade expenditure function of the non-resource economy, with e^H and r^H the expenditure and revenue functions. Then r^H is not a function of R so

$$E^H(p_S, u) = e^H(p_S, u) - r^H(p_S),$$

where again I suppress other parameters that are kept constant.

Now ‘current account balance’ means trade balance between the non-resource economy and the resource owner, so

$$E^H(p_S, u) = 0. \quad (35)$$

Above we also had $E_p = 0$ because the non-tradability of Y_S implied domestic

demand equalled domestic supply. Now Y_S is ‘exported’ to the resource owner so

$$E_p^H(p_S, u) = e_p^H(p_S, u) - r_p^H(p_S) < 0. \quad (36)$$

Now when we totally differentiate E^H we find

$$du = -dp_S E_p^H > 0, \quad (37)$$

so $\frac{du}{dp_S} > 0$ and the rise in p_S causes a rise in the utility, or real income, of households.

5.2 Dynamic results

5.2.1 Proof of Proposition 1

From (25) and (26), an equilibrium with entrepreneurs in two sector Q and Z requires that $p_Q \mu_Q Y_Q = p_Z \mu_Z Y_Z$. Stability requires that a perturbation that moves entrepreneurs from Q to Z , whose partial effect is to increase Y_Z/Y_Q by some proportional factor, will in general equilibrium reduce p_Z/p_Q by a larger proportional factor. If this occurs then entrepreneurs want to move back from Z into Q , returning to equilibrium. The condition that p_Z/p_Q decline by more than the rise in Y_Z/Y_Q is just the condition that the elasticity of substitution between Z and Q is less than unity, so this is the condition for stability.

Part (i) follows from the fact that the relative price of Y_E and Y_M is fixed (at unity), so the elasticity of substitution between them is infinite. Any equilibrium with $\mu_E Y_E = \mu_M Y_M$ is therefore unstable.

Part (ii) follows from the fact that the elasticity of substitution between Y_S and T is $\varepsilon < 1$. For (a), if $Y_M = 0$ then $Y_E = T$. The elasticity of substitution between Y_S and Y_E is therefore $\varepsilon < 1$ so $\text{TMC}(S, E)$ is a stable equilibrium.

To prove (b) is less straight forward. First, if $R = 0$ then the argument from (i) applies. But now suppose that $R > 0$. Then from (17) it will always be the case that $Y_E > 0$. I first show that while the economy is in $\text{TMC}(S, M)$, Y_E/T will be declining. I then show that when Y_E/T is sufficiently small, $\text{TMC}(S, M)$ is stable.

First note that for all sectors, defining $V_Z \equiv (L_Z, K_Z)$ for $Z = E$ or M and

$V_E = R$, and substituting for p_Y from (6),

$$Y_Z = Y_Z(A_Z, p_S, V_Z)$$

so

$$\hat{Y}_Z = \frac{dA_Z}{Y_Z} \frac{\partial Y_Z}{\partial A_Z} + \frac{dp_S}{Y_Z} \frac{\partial Y_Z}{\partial p_S} + \frac{dV_Z}{Y_Z} \frac{\partial Y_Z}{\partial V_Z} \quad (38)$$

where $\hat{X} \equiv \frac{dX}{dt} dt \frac{1}{X} = dX/X$ refers to the rate of growth. (38) says that growth in Y_Z is due to the partial contributions of technology A_Z , the relative price p_S , and factors employed in sector Z .

With $\text{TMC}(S, M)$ we have $dA_S > 0$, $dA_M > 0$ and $dA_E = 0$. To remain in $\text{TMC}(S, M)$ requires that Y_M grow at the same rate as $p_S Y_S$, i.e. that

$$\hat{Y}_M = \hat{p}_S + \hat{Y}_S. \quad (39)$$

Now observe that using (6) to substitute for p_Y in (17) and (18) implies that

$$\frac{\partial Y_E}{\partial p_S} \frac{p_S}{Y_E} = \frac{dp_Y}{dp_S} \left(\frac{\alpha + \beta - 1}{\alpha + \beta} \right) = \frac{\partial Y_M}{\partial p_S} \frac{p_S}{Y_M}. \quad (40)$$

That is, the partial elasticities of Y_E and Y_M with respect to p_S are equal; call this quantity σ . From (38) and (40), with A_M and A_S growing we have

$$\begin{aligned} \hat{Y}_M &= \sigma \hat{p}_S + \frac{dA_M}{Y_M} \frac{\partial Y_M}{\partial A_M} + \frac{dV_M}{Y_M} \frac{\partial Y_M}{\partial V_M} \\ \hat{Y}_E &= \sigma \hat{p}_S. \end{aligned}$$

Both $\frac{dA_M}{Y_M} \frac{\partial Y_M}{\partial A_M} > 0$ and $\frac{dV_M}{Y_M} \frac{\partial Y_M}{\partial V_M} > 0$ so $\hat{Y}_M > \hat{Y}_E$. Hence $Y_E/T \rightarrow 0$ over time.

I now show that $\text{TMC}(S, M)$ is stable when Y_E/T is sufficiently small. Define

$$\theta_Z = \frac{Y_Z}{T}$$

for $Z = E$ or M . Then

$$\hat{T} = \theta_E \hat{Y}_E + \theta_M \hat{Y}_M. \quad (41)$$

From (7) and (41),

$$\begin{aligned}\hat{p}_S &= \frac{1}{\varepsilon} (\hat{T} - \hat{Y}_S) \\ &= \frac{1}{\varepsilon} (\theta_M \hat{Y}_M - \hat{Y}_S) + \frac{\theta_E \hat{Y}_E}{\varepsilon}.\end{aligned}$$

As $Y_E/T \rightarrow 0$, $\theta_M \rightarrow 1$ and $\theta_E \rightarrow 0$, so $\hat{p}_S \rightarrow \frac{1}{\varepsilon} (\hat{Y}_M - \hat{Y}_S)$. Hence as $Y_E/T \rightarrow 0$ the elasticity of substitution between Y_E and Y_S tends to $\varepsilon < 1$, so the equilibrium $\text{TMC}(S, M)$ is stable.

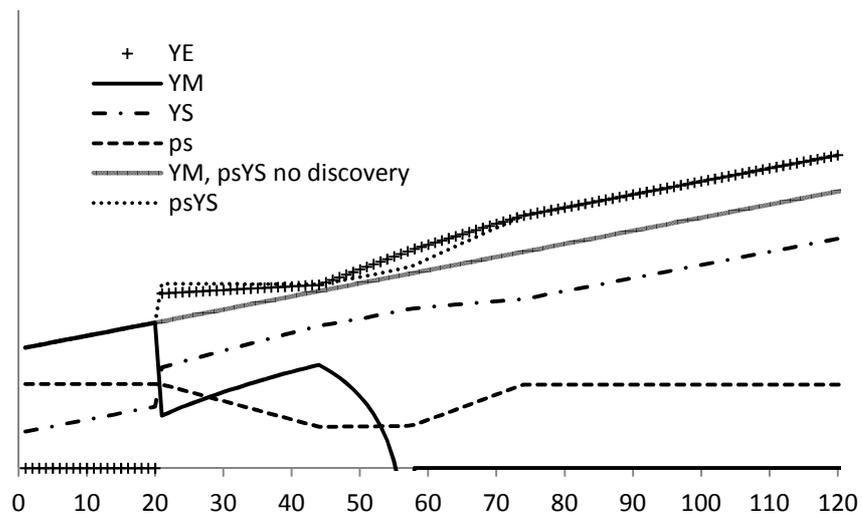
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Figure 1: Log output by sector



Note: Since zero values cannot be represented on a log scale, when output is close to zero it is plotted touching the horizontal axis.

Figure 2: Log GDP and household income

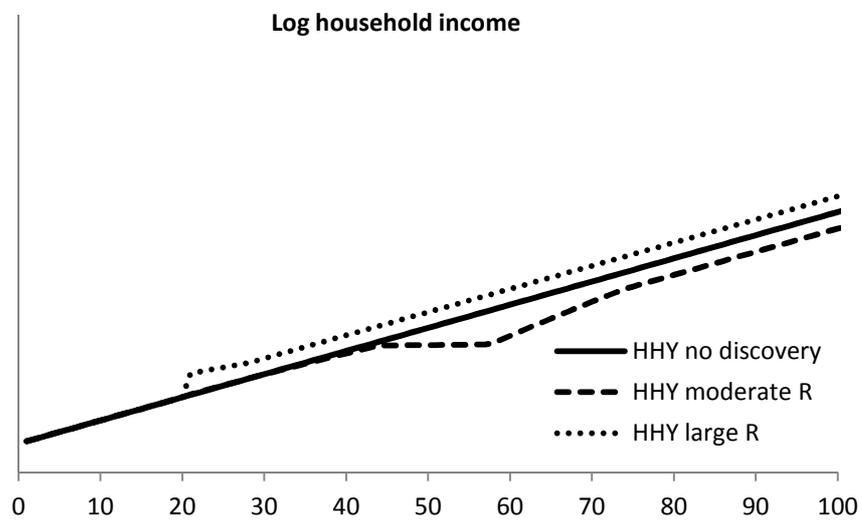
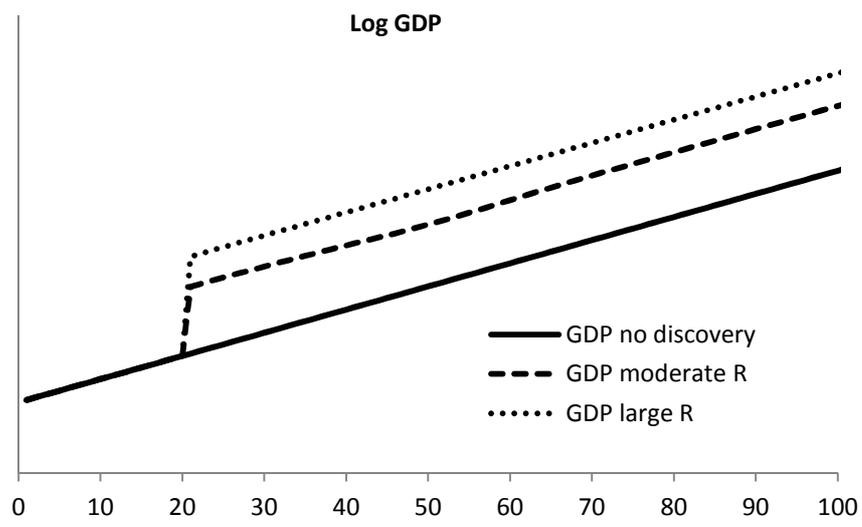
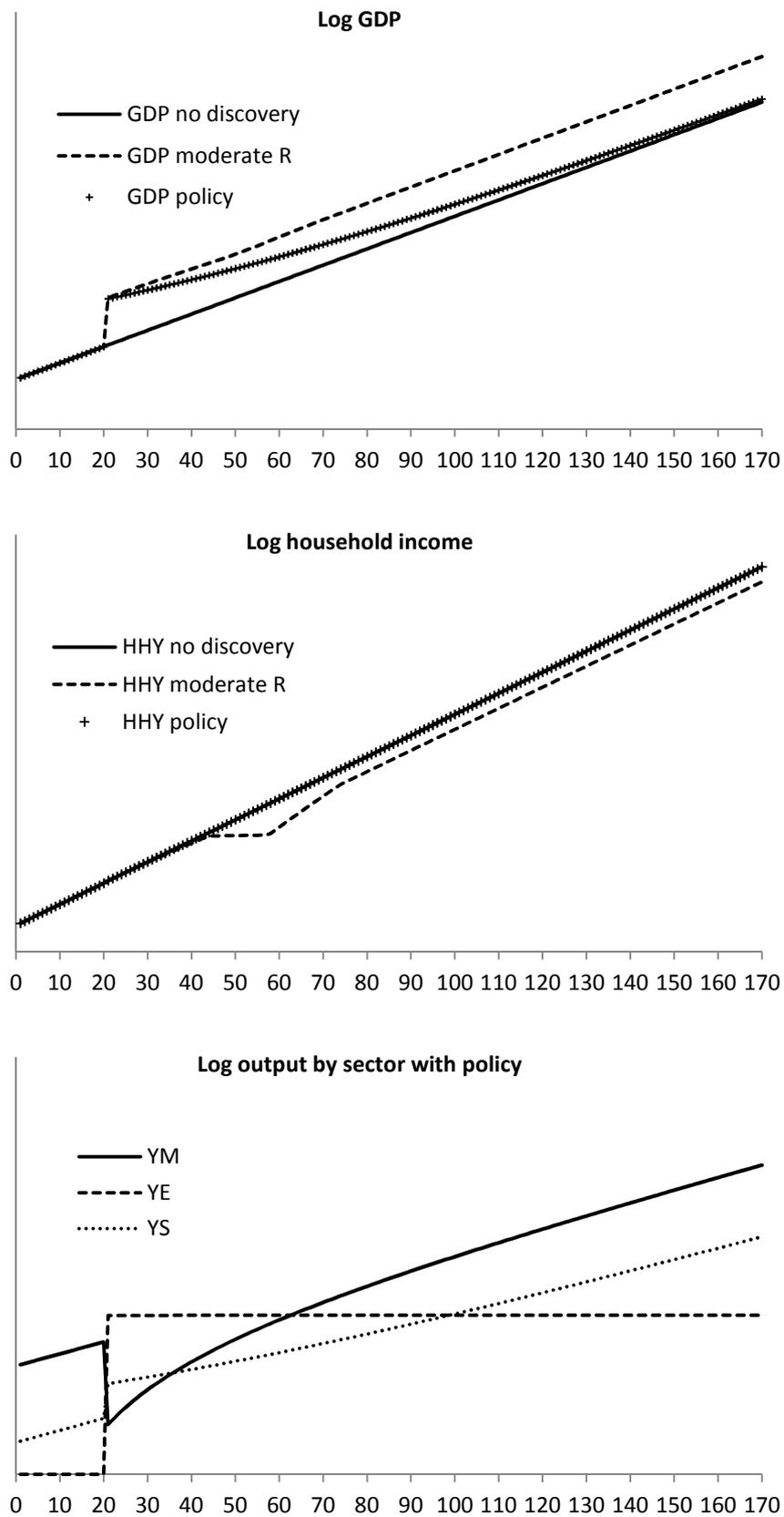


Figure 3: Output and income with and without policy



Note: Log household income (HHY) with moderate R and with the policy approximately overlap. As in figure 1, when values are close to zero they are plotted touching the horizontal axis.