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ABSORBING A WINDFALL OF FOREIGN EXCHANGE:

Dutch disease dynamics*

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Abstract

The permanent income rule is seldom the optimal response to a windfall of foreign exchange, such as that from a resource discovery. Absorptive capacity constraints require domestic investment, and investment in structures requires non-traded inputs the supply of which is constrained by the initial capital stock. This, particularly when combined with intra-sectoral capital immobility, delays adjustment and creates short run 'Dutch disease' symptoms as the real exchange rate sharply appreciates and overshoots its long run value. Optimal revenue management requires investing in the domestic non-traded goods sector and a slow build up of consumption. Accumulation of foreign assets adjusts to accommodate the time-paths of domestic consumption and investment.

Keywords: absorptive capacity, absorption constraints, irreversible investment, windfall, natural resources, Dutch disease, economic development.

JEL codes: E21, E62, F43, H63, O11, Q33

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1. Introduction

How should an economy respond to a foreign exchange windfall such as that associated with discovery of a natural resource or a commodity price boom? The standard prescription is the permanent income hypothesis (PIH) that suggests an immediate and permanent increase in consumption to its new level, with foreign assets (such as a Sovereign Wealth Fund) being used to smooth the difference between the cost of incremental consumption and the time-profile of the windfall. This is the benchmark case but needs to be modified for numerous reasons, such as limited access to international capital markets and consequent capital scarcity (van der Ploeg and Venables, 2011); expectations about the sustainability of the windfall (Gelb and Grasmann, 2008); and the political economy of alternative choices (Collier and Gunning, 2005). This paper focuses on a further issue, which is the ability of the economy to absorb additional spending. Resource rich developing economies often face supply bottlenecks and consequent upwards pressure on prices and the real exchange rate as they seek to scale-up domestic spending. We provide a micro-founded model of these constraints on absorptive capacity, and analyze their implication for optimal management of windfall revenues. [1]

The central issue, important in many contexts, is that the economy faces adjustment to a new long run structure, such as a larger non-traded goods sector. The reference point is an economy which can jump instantaneously to this new structure. This is possible if all sorts of capital – skills, equipment, and structures – can be redeployed or bought and sold on world markets, so that bottlenecks are not encountered and relative prices need not change. We argue that this may not be feasible, for two reasons. First, much physical capital is sunk so cannot be redeployed without cost, and second, some sorts of capital are non-traded and cannot be acquired on world markets. This latter point is crucial although country specific. Some resource rich countries (some of the Gulf States) have made essentially all capital tradable; human capital is imported by immigration of skilled workers, and structures are imported by immigration of construction workers. But in many other countries this option is infeasible, so the essential problem is that creating new capital requires *non-traded* capital. This may be physical capital, or may be human capital; it takes teachers to produce teachers. It is this shortage of 'home-grown' capital that we believe is the quintessential feature of absorptive capacity.

Whilst our approach to absorption is applicable to structural change in various contexts, our focus is on newly resource rich economies that face the problem of managing resource revenues. Spending from

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[1] The term 'absorptive capacity' is used frequently in the development economics literature, particularly in the context of international aid, e.g. Bourguignon and Sunderg (2006). While our focus is resource booms, similar issues arise in discussion of scaling up aid, e.g. de Renzio (2005), Mavrotas (2007). The industrial organization literature uses the term absorptive capacity quite differently, to mean a firm's ability to absorb new ideas or technologies.

these revenues increases demand for non-traded goods and crowds out domestic production of traded goods, causing structural change and creating 'Dutch disease' concerns (e.g. Corden and Neary, 1982).[2] [3] Our analysis brings together the previously unrelated literatures on optimally managing a windfall (e.g. Davis et al. 2002; Collier et al. 2009) and on Dutch disease, both of which have been at the centre of most of the economic analyses of the consequences of resource abundance. There is a clear but hitherto unexplored interaction between the issues.[4] The rate of spending determines the magnitude of Dutch disease effects, and relative price changes associated with the Dutch disease influence optimal spending patterns. This paper studies these interactions. It develops a model in which a windfall of foreign exchange will bring about structural change, but change is not instantaneous; the need for home-grown capital creates supply rigidities which mean that relative prices change (the real exchange rate experiences short and medium run appreciation), and this shapes the appropriate revenue management policy. We show that optimal policy typically has three elements. First, there is a rapid build up of investment and capital in the non-tradable sector.[5] Second, there is slow build up of consumption to its new long run value. Third, foreign assets should be managed to ensure that domestic spending (consumption and investment) is on an efficient path. In a central case this involves 'parking' resource revenues offshore until absorption constraints have been relaxed. Compared to the PIH it may be optimal to place less revenue in offshore funds in the long run, because of the need to finance structural change, but more in the short run, because of absorption constraints.

[2] Early evidence on Dutch disease effects was mixed (e.g. Sala-i-Martin and Subramanian 2003), but more recent evidence points to the presence of effects. Ismail (2010) using sectoral data for manufacturing finds that a 10% increase in the size of the windfall is associated with a 3.4% fall in value added across manufacturing, but less so in countries that have restrictions on capital flows and for sectors that are more capital intensive. Using as counterfactual the Chenery-Syrquin (1975) norm for the size of tradables, countries in which the resource sector accounts for more than 30% of GDP have a tradables sector 15 percentage points lower than the norm (Brahmbhatt, et al., 2010). Harding and Venables (2013) look at the trade side, finding that, on average, a windfall brings a fall in non-resource exports by 70 percent of the amount, while non-resource imports increase by 30 percent of the amount.

[3] Related aspects of the Dutch disease have to do with short run macroeconomic adjustment and the role of monetary and exchange rate policy (e.g. Eastwood and Venables 1982, Neary and Purvis, 1982; Gupta and Heller 2002).

[4] There have been two previous studies of this interaction. The first is the dynamic model put forward in the appendix of Sachs and Warner (1997) which abstracts from real exchange rate volatility and absorption constraints, since all adjustment comes from the capital stock while the real exchange rate is pinned down by the world interest rate. The second is Matsen and Torvik (2005) who study the optimal management of a resource windfall in a Dutch disease model with learning by doing externalities, but abstract from accumulation of domestic capital and foreign assets and the government budget constraint. They find that it is optimal to have a permanent *moderate* appreciation rather than a temporary *sharp* appreciation of the real exchange rate and a permanent lower growth rate.

[5] This does not occur in the one-sector economy with perfect capital mobility where none of the windfall is spent on domestic investment. If there is capital scarcity, it is optimal to spend part of the windfall on investment as investment is sub-optimally low (van der Ploeg and Venables, 2011). Here we show that in a two-sector economy it may be optimal to allocate part of the windfall to investment even with perfect capital mobility.

Our framework for analysing the optimal management of foreign exchange windfalls in the presence of absorption constraints builds on earlier work on optimal growth in a two-sector closed economy (Uzawa, 1965) and is related to a strand of two-sector dependent economy models (Turnovsky and Sen, 1995; Turnovsky, 1997, 2009). These models have perfect factor mobility across sectors and capital produced entirely by the non-traded sector. They have regimes with sluggish adjustment of the real exchange rate if the non-traded sector is capital intensive, and instantaneous real exchange rate adjustment if the traded sector is capital intensive. Our framework extends this work in the following directions. First, we allow part of capital to be traded (so that it can be imported following a windfall) and part of it to be home-grown. This matters crucially for the adjustment dynamics. Second, although investment can be directed at any of the sectors, once it is installed it is difficult to unbolt and reallocate it to another sector.[6] This irreversibility is crucial for the adjustment path, regardless of the relative capital intensity of sectors. Our primary contribution is, however, not so much to put forward a new two-sector dependent economy model, as to analyse the optimal way of harnessing a windfall of foreign exchange and of managing the consequent choices between consumption, domestic investment, and foreign asset accumulation.

The outline of our paper is as follows. Section 2 sets up the benchmark for managing a windfall, based on the PIH. We generalize the standard PIH by allowing for a tradable and non-tradable sector, although in this section we retain the assumption of perfect tradability of capital. The economy experiences structural change following the windfall and this changes its physical capital requirement. Although adjustment is instantaneous, the simple PIH recommendation of holding the entire windfall in foreign assets does not generally apply, as part should go to meeting the altered capital requirements of the domestic economy. Section 3 turns to our main argument, assuming that although financial capital is internationally mobile, physical capital is not. Production of capital equipment requires non-tradable inputs (or structures), so must be at least partly home-grown. Even though the economy has perfect access to international capital markets the requirement that it accumulates capital goods with a domestic component means that it cannot jump instantaneously to a new steady state. Instead there is an adjustment path along which relative prices are changing and economic agents vary consumption and investment in response to the path of prices. We show that if the non-traded sector is intensive in home-grown capital, the real exchange rate sharply appreciates and overshoots while capital is gradually built up. Section 4 presents the most general version of our model in which capital is partly home-grown, and is also immobile between sectors. Exchange rate overshooting, and undershooting of real consumption, is then a general consequence of a windfall because it takes time for the economy to adjust to meet increased demand for non-tradable goods. We examine the determinants of the magnitude of these effects and their

[6] One could allow for intrasectoral costs of capital adjustment (e.g. Morshed and Turnosvky, 2006).

implications for the level and composition of asset accumulation. We also extend the model to include a capital market imperfection. A resource boom then causes both structural change and more general capital deepening; this has real income benefits, but creates further short and medium run problems of absorptive capacity. Section 5 interprets our results in the light of the earlier literatures on Dutch disease including sectoral adjustment costs and knowledge spill-over effects, and on uncertainty about future oil prices and reserves discoveries. Section 6 draws out policy implications and conclusions.

2. Managing a windfall; permanent income hypothesis and structural change

We set the scene by looking at management of a foreign exchange windfall in a small open two-sector economy in which capital can move freely, both internationally and sectorally. The windfall is an exogenous flow of foreign exchange *N*, and (non-windfall) gross national product (GNP) is defined as GNP $\equiv pX^N + X^T$, where X^N and X^T denote output of non-tradables and tradables respectively. The price of non-tradables (or the real exchange rate) is denoted *p*, and the price of tradables is normalized to unity. Production in each sector uses capital and labour and operates under constant returns to scale. Capital can be obtained by borrowing and lending freely at the exogenous world interest rate r^*, and is used to buy freely traded capital goods (equipment). We denote the stock of capital by *K*. The economy has fixed labour supply *L*, and both of these factors are (for the moment) mobile between sectors. The GNP function $Y = Y(p, K)$ defines the maximum level of GNP that can be attained by optimally choosing the sectoral factor inputs given output prices and aggregate factor usage; the constant *L* is suppressed in the notation. Supply of non-tradables and tradables are given by Y_p and $Y - pY_p$ respectively. The properties of the GNP function are discussed further below and in appendix 1. On the demand side, real consumption is *C*, and consists of both tradable and non-tradable goods with unit-expenditure function $e = e(p), e_p > 0, e_{pp} < 0$. Consumption of non-tradables equals e_pC and of tradables $(1-\theta^c)e(p)C$ where $\theta^c \equiv pe_p / e$ defines the consumption share of non-tradables.

Households choose consumption *C* and asset accumulation to maximize utility,

$$(1) \qquad \max_{C,K,A} \int_0^\infty U(C)e^{-\rho t}dt, \qquad U' > 0, U'' < 0,$$

where the rate of discount is $\rho > 0$. Maximization is subject to the budget constraint and to market clearing for non-traded goods,

(2) $\dot{A}^F + \dot{K} = r^* A^F + N + Y(p,K) - e(p)C - \delta K$, $A^F(0) = A_0^F$, $K(0) = K_0$, $\lim_{t\to\infty} e^{-r^* t} A^F(t) = 0$,

(3) $e_p(p)C = Y_p(p,K)$,

where A_0^F and K_0 denote the initial stocks of financial assets and physical capital before the resource discovery. The budget constraint says that saving in financial assets A^F and physical capital K occurs if income from abroad (interest plus windfall revenue) plus production income net of depreciation exceeds consumption. The no-Ponzi condition states that financial debt/assets cannot rise faster than the world interest rate. We can thus rewrite (2) in present value form as:

(2′) $\int_t^\infty e(p)C(s)e^{-r^*(s-t)}ds \le A^F(t) + V(t) + K(t) + \int_t^\infty \left[Y(p(s),K(s)) - (r^* + \delta)K(s)\right]e^{-r^*(s-t)}ds$

where the present value of the windfall at time t (natural resource wealth) is given by

(4) $V(t) = \int_t^\infty N(s)e^{-r^*(s-t)}ds.$

The present value of consumption must thus not exceed the sum of financial assets, natural resource wealth, physical capital and the present value of non-capital factor income. In this economy Ricardian debt neutrality holds, so the distribution over time of a windfall of size $V(0)$ resulting from a discovery at time zero is of no consequence for consumption and the real economy. We can see this by defining the sum of financial assets and remaining natural resource wealth as $A \equiv A^F + V$, making use of $\dot{V} = r^* V - N$ (from (4)), and rewriting (2) as follows:

(2″) $\dot{A} + \dot{K} = r^* A + Y(p,K) - e(p)C - \delta K$, $A(0) = A_0^F + \Delta A$, $K(0) = K_0 + \Delta K$, $\lim_{t\to\infty} e^{-r^* t} A(t) = 0$.

We could thus suppose without loss of generality that initially upon discovery some of the resource is sold forward and the value at date of discovery, $V(0)$, is placed in a combination of resource wealth plus financial assets, ΔA, and physical capital, ΔK, so that $V(0) = \Delta A + \Delta K$.

Maximisation of (1) subject to the economy's budget constraint (2″) (or equivalently (2′) and (4)) and equilibrium in the market for non-tradables, condition (3), yields the familiar Keynes-Ramsey rule and the condition for the optimal capital stock (see appendix 2). The Keynes-Ramsey rule contains the consumption rate of interest, $r^* - \dot{e}/e$, so

(5) $$\frac{\dot{C}}{C} = \sigma\left(r^* - \rho - \frac{\dot{e}}{e}\right) = \sigma\left(r^* - \rho - \theta^C \frac{\dot{p}}{p}\right)$$

where $\sigma \equiv -U'/CU'' > 0$ defines the elasticity of intertemporal substitution. The other optimality condition is that the marginal product of capital must equal the user cost of capital:

(6) $$Y_K(p,K) = r^* + \delta.$$

We suppose that $r^* = \rho$ and that the economy is initially stationary with $V(0) = 0$. Equilibrium values of C, p, and K come from (3), (2″) and (6).

At date 0 there is unanticipated discovery of the windfall, $V(0) > 0$. We think of this as a resource discovery, although it could also be an unanticipated jump in the price of the resource. Our setup implies that the windfall is unanticipated until time zero and is perfectly known from that time onwards. The revenue flow might start immediately, or at some later date. In our stylized setting the windfall thus corresponds to an unanticipated resource discovery, which distinguishes it from an anticipated stream of development aid or remittances. We abstract from the fact that natural resource discoveries are in practice not perfectly unanticipated, since probabilities of finding them depend on known geological features.

The benchmark case is when all variables jump to their new stationary values, as established in proposition 1.

Proposition 1: If $r^* = \rho$, capital is perfectly mobile internationally and sectorally and there are constant returns to scale then: a windfall of foreign exchange at date 0 causes instantaneous and permanent changes in the values of C and K, no change in p, and no subsequent adjustment dynamics. Changes ΔC and ΔK are given by:

(7) $$\Delta C = r^* V(0)/e(p),$$

(8) $$\Delta K = \frac{r^* V(0)}{Y_{pK}} \frac{e_p(p)}{e(p)}.$$

Proof: An equilibrium path with no adjustment dynamics, $\dot{p} = \dot{C} = \dot{A} = \dot{K} = 0$, satisfies equilibrium condition (5). It satisfies (2″) if ΔA, ΔK, ΔC are such that $0 = r^* \Delta A + \left(Y_K(p,K) - \delta\right)\Delta K - e(p)\Delta C$. This implies that $e(p)\Delta C = r^*\left(\Delta A + \Delta K\right) = r^* V(0)$, giving equation (7). Equations (3) and (5) are satisfied by changes satisfying $\left[e_{pp}C - Y_{pp}\right]\Delta p + e_p \Delta C = Y_{pK}\Delta K$ and $Y_{Kp}\Delta p + Y_{KK}\Delta K = 0$. However, constant returns to scale implies that $\Delta p = 0$. This is most easily seen by noting that unit cost functions in each sector, $a^T(r^*, w)$, $a^N(r^*, w)$, depend on input prices (r^* and w for labour) but not the scale of activity. Equality of unit cost to price is $a^T(r^*, w) = 1$ for tradables and $a^N(r^*, w) = p$ for non-tradables; since the price of the tradable and r^* are both fixed at world levels, these conditions determine p and w independently of other variables in the model. It follows that the GNP function has property $Y_{KK} = 0$,[7] $\Delta p=0$, and ΔK is given by (8). Q.E.D.

A number of remarks follow from this benchmark proposition. The first is that consumption follows the permanent income hypothesis, jumping on impact to a new level at which the cost of the increment to consumption, $e(p)\Delta C$, equals the annuity value of the windfall, $r^*V(0)$. However, smoothing is not achieved by placing all windfall revenue in foreign assets as is often suggested. Because of the presence of non-traded goods the economy has to undergo structural change which may require a change in the domestic capital stock, ΔK, as given by (8). The sign of the change is that of Y_{pK}, and is positive (negative) if the non-traded (traded) sector is capital intensive. This follows from the Rybczynski theorem, which states that an increase in capital boosts output of non-traded goods if non-tradables are capital intensive (appendix 1). In that case, part of the windfall needs to be put into increasing the domestic capital stock; conversely, if tradables are capital intensive foreign assets increase by more than $V(0)$ as the domestic capital stock needs to be reduced.

The proposition assumes perfectly frictionless adjustment of capital, so physical capital can be increased or decreased by purchases or sales of equipment at world prices. Removing this assumption is the subject of following sections of this paper. We also discuss the implications of removing the assumption of perfect mobility of financial capital ($r^* = \rho = Y_K(p,K)$), and of sector specific factors, in which case $Y_{KK} < 0$ and structural change brings a change in long run relative prices.[8]

Finally, proposition 1 established that the sum of foreign assets plus remaining resource wealth, $A = A^F + V$, jumps on impact and is constant thereafter. However, the balance of the two terms varies through time according the actual path of revenue accrual, $N(t)$. This division of A between A^F and V has no effect on proposition 1; for example, given our assumptions we could think of the resource being entirely sold forward so that the value is realised instantaneously and turned into financial assets. More generally, since A is constant, $\dot{A}^F + \dot{V} = 0$, and $\dot{V} = r^*V - N$, the change in financial assets equals the temporary

[7] This is simply a variant of factor price equalization (more accurately termed factor price invariance, see Leamer and Levinsohn 1995; Blackorby, et al., 1993) in a two sector constant returns model with two things tradable (capital and the tradable good). See appendix 1 for properties of the GNP function.

[8] Related is the literature on sudden stops which is concerned with the phenomenon that public debt explodes until a given limit is reached and then adjustment needs to take place (Kehoe and Ruhl, 2009).

component of the remaining windfall, $\dot{A}^F = N - r^*V$. The share of the current flow of windfall revenue that is saved in financial assets, $\dot{A}^F / N$ is then:

(9) $$\dot{A}^F / N = 1 - r^* V / N.$$

To illustrate, suppose that resource revenue starts at time zero and declines exponentially at rate $\eta \geq 0$ thereafter, so its present value at date *t* is $V(t) = N(t)/(r^* + \eta)$. At the date of the windfall foreign assets change by amount $V(0) - \Delta K$, as capital is bought or sold to make the structural change required in the economy. Thereafter the fraction of resource revenues saved and accumulated in foreign assets is constant, $\dot{A}^F / N = \eta / (r^* + \eta)$.[9] A smaller fraction is saved if the windfall is more permanent (low value of η), and a windfall which lasts forever ($\eta = 0$) causes no change in foreign assets. Another illustration is the temporary step windfall: $N(t) = \bar{N}, 0 < t < T, N(t) = 0, t \geq T$. The present value of remaining resource wealth is $V(t) = \bar{N}\left[1 - e^{-r^*(T-t)}\right]/r^*$, so for $t \leq T$, $\dot{A}^F / N = \left[1 - e^{-r^*(T-t)}\right]$. The fraction of revenue which is saved increases during the time of the windfall and goes to unity at the day of exhaustion. The reason is that, as time progresses, the stock of the resource left becomes smaller relative to the flow, and thus the windfall becomes more temporary, necessitating more saving.

3. Structures: non-traded capital

In the preceding section the economy can jump to its new steady state because capital required for structural change is freely traded. We now go to the case where financial capital is perfectly mobile (the interest rate remains fixed at r^*) but physical capital is made of non-traded goods. Capital goods have to be 'home-grown', and cannot be imported or exported. To distinguish this from the previous case of capital goods traded on world markets ('equipment'), we denote this type of capital by *S* for 'structures'.

Production functions and the GNP function are qualitatively unchanged, and we write the GNP function $Y = Y(p, S)$. The budget constraint (2″) and non-traded goods market clearing (3) are now:

(10) $$\dot{A} + p\dot{S} = r^* A + Y(p, S) - e(p)C - \delta p S, \quad A(0) = A_0^F + V(0), \quad \lim_{t\to\infty} e^{-r^* t} A(t) = 0,$$

(11) $$\dot{S} = Y_p(p, S) - e_p(p)C - \delta S, \quad S(0) = S_0.$$

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[9] The stock of foreign assets is $A^F = [1 - \exp(-\eta t)] N_0 / (r^* + \eta) - \Delta K$.

The important difference is that non-traded goods market clearing, equation (11), now sets the rate at which the stock of structures can change, $\dot{S}$. Furthermore, we suppose that upon discovery the revenue from selling the windfall forward is entirely put in resource and financial wealth (not in physical capital).

The equilibrium maximizes (1) subject to these equations, giving the optimality conditions:

(12) $$C = \left[e(p)\lambda\right]^{-\sigma}, \quad \dot{\lambda} = 0,$$

(13) $$Y_S(p,S) = r^* + \delta - \dot{p}/p,$$

where $\lambda > 0$ denotes the social value of wealth. Equation (12) corresponds to the Keynes-Ramsey rule (4), but it will be convenient to work with it expressed in this form; notice that the social value of wealth will jump downwards at date of discovery but is constant thereafter (appendix 2). Equation (13) states that the marginal product of structures must be set to its user cost which consists of the rental charge plus the depreciation charge minus the expected rate of capital gains in the value of structures. (The latter term does not feature in (5), since the price of traded capital equipment is fixed on world markets).

To understand the dynamics of this economy we study the effect of a cut in the social value of wealth, λ, instead of a boost to windfall wealth, $V(0)$. Using equation (12) in (11) and rewriting (13) these can be deduced from the pair of equations:

(14) $$\dot{S} = Y_p(p,S) - e_p(p)[e(p)\lambda]^{-\sigma} - \delta S, \quad S(0) = S_0,$$

(15) $$\dot{p} = \left[r^* + \delta - Y_S(p,S)\right]p.$$

We can thus calculate the time trajectories of S, p and hence C and Y as a function of the constant λ. Upon substitution of these trajectories into the present value version of (10), we can solve for the unique value of λ corresponding to any value of the windfall $V(0)$ (see appendix 3). To put it differently, any drop in the value of λ corresponds to a particular size of the windfall. We continue to suppose constant returns to scale so that $Y_{SS} = 0$. The long run equilibrium prices follow from (15), $Y_S(p) = r^* + \delta$, and are thus the same as the initial equilibrium prices. Steady state values of consumption[10] and the stock of structures can be found, as in the preceding section; equation (14) gives $Y_p(p,S) - \delta S = e_p(p)[e(p)\lambda]^{-\sigma}$, which given λ and the steady state value of p can be solved for the steady state value of S. The main point is that now, since structures cannot be acquired on world markets, variables adjust slowly, and p and factor prices

[10] Steady state consumption C can be calculated from (12), where σ may depend on the steady state value of C itself.

change along the adjustment path. There are two cases, depending on whether the economy has to accumulate or decumulate structures.

Non-traded goods intensive in structures:

The first case is where the economy has to accumulate structures, this occurring if non-traded goods are relatively capital intensive which, from equation (14), applies if $Y_{pS} - \delta > 0$.[11] The phase diagram and the implied dynamics for the system (14)-(15) are portrayed in panel (a) of Figure 1. Given $Y_{pS} > \delta$ the S stationary (equation (14)) has negative slope, since it is increasing in S and increasing in p (providing a higher price reduces excess demand for non-tradables). If the economy is above this locus more non-tradables are produced than are consumed and needed to cover depreciation, so the stock of structures expands. From (15) the $\dot{p} = 0$ locus is horizontal and independent of λ. Above the stationary the price is falling, because higher p raises the return on investment (Stolper – Samuelson with $Y_{pS} > 0$), so is consistent with zero present value of profits if capital losses are expected, i.e. $\dot{p} < 0$.

Putting this together, the saddle path *s-s* slopes downwards and is steeper than the $\dot{S} = 0$ locus. A windfall shifts the $\dot{S} = 0$ locus to the right because the stock of structures must increase in the long run (as in equation (8)). The real exchange rate follows the bold line on the figure; from initial stationary at E_0 the real exchange rate jumps up, overshooting on impact; it then depreciates back along the saddle path as the economy accumulates structures, going asymptotically to new long run equilibrium E_∞.

Home-grown capital now acts as a brake on the speed at which the economy can move to its new steady state, so price effects like those of the Dutch disease – an appreciated exchange rate – occur, although they are temporary. Compared to the PIH of section 2 the economy's response is different in three respects. First, the rate at which capital increases is slower, evident from the home-grown constraint. Second, real consumption jumps up on impact, but undershoots its long run value, as can be seen from equation (12); it is efficient to postpone some of the consumption increment because of its temporarily high price. Consumer spending, $e(p)C = \lambda^{-\sigma} e(p)^{1-\sigma}$, overshoots if the intertemporal elasticity of substitution is less than unity ($\sigma < 1$), and conversely. Third, the structure of assets now follows a different path. In the frictionless economy A jumps down to finance the jump in K (proposition 1). Now, both the decline in A and the increase in S are gradual. The division of A between resource wealth and financial assets depends on the time path of N. However, for any such time path of N, A^F is now higher,

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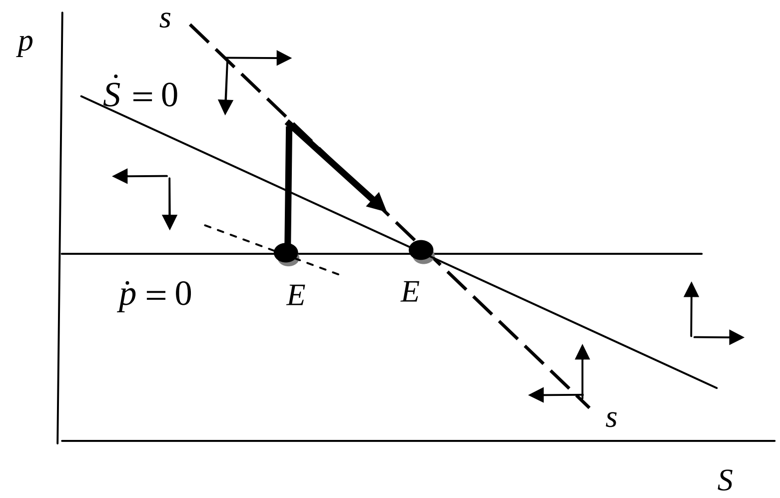
[11] This is equivalent to $Y_{pS} > 0$, under the very weak condition that non-tradable production is large enough to replace depreciation of structures. This follows from the Rybczynski theorem under which $Y_{pS} > 0$ implies $Y_{pS} > X^N/S$ (as can be checked from appendix 1).

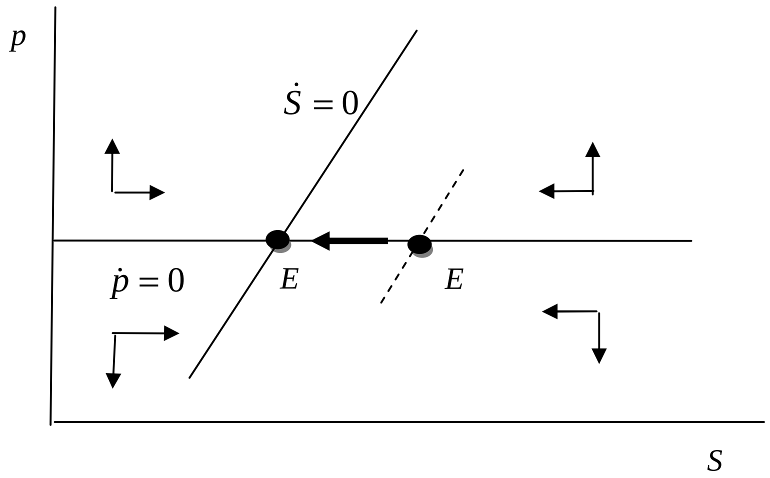
with the gap between cases maximised at some point on this path. Essentially, it is optimal to place more of the windfall in financial assets (or incur less debt[12]) because absorption constraints make it efficient to increase spending less fast. This is a temporary feature of the adjustment path, and we refer to such accumulation of financial assets as a ‘parking fund’, and discuss it further in what follows.

Figure 1: **Dynamic effects of a windfall with non-traded structures.**

(a) Non-traded good sector intensive in structures: $Y_{pS} > \delta$



(b) Traded good sector intensive in structures: $Y_{pS} < 0$



[12] Absorption problems reduce the incentive to engage in excessive borrowing discussed by Mansoorian (1991).

Traded goods intensive in structures:

The alternative case is that in which the non-traded sector is un-intensive in structures. This implies that the economy has to decumulate structures in response to the windfall, because this gradually releases labour in the traded sector for the non-traded sector which is the only way for the non-traded sector to expand following the windfall. This very different response is illustrated in panel (b) of Figure 1. The slope of the *S* stationary is now positive, and (as before) *S* is increasing or decreasing according to whether the economy is above or below this locus. The *p* stationary is unchanged, but higher *p* depresses the return on investment, so is consistent with zero present value of profits if capital gains are expected, i.e. $\dot{p} > 0$. For this case, the saddle path is the horizontal $\dot{p} = 0$ locus. A windfall shifts the $\dot{S} = 0$ locus to the left, so that the stock of structures slowly contracts towards its new lower steady state with no adjustment in the real exchange rate whatsoever (see appendix 4). Consumption jumps up instantaneously, from (12), now going the whole way to its new long run value. Adjustment involves slowly expanding non-tradable production, while the economy's endowment of structures is decumulated and labour released from the tradable to the non-tradable sector: decumulation takes the form of both depreciation and consumption of *S*.

We summarize our discussion in the following proposition.[13]

Proposition 2: Consider an economy where the only type of capital is non-traded structures:

(a) if structures are used intensively in the non-traded sector, there is a temporary appreciation of the real exchange rate while the stock of structures gradually increases towards its new higher long run value. Real consumption undershoots its new higher long run value;

(b) if structures are used intensively in the traded sector, a windfall does not affect the real exchange rate and leads to gradual winding down of the stock of structures. Real consumption jumps up instantaneously to its new equilibrium value.

The consequences of the windfall for genuine saving (i.e. the change in total wealth consisting of financial assets, resource wealth and structures) and the need for a parking fund are explored in appendix 5. It shows that, if the traded sector is intensive in structures, genuine savings is zero and the winding down of structures is always associated with accumulation of foreign assets. If the non-traded sector is

[13] If structures *S* do not move (and drop (14)), we have from (13) or (15) $\dot{p} = \left[r^* + \delta - Y_S(p,S) \right] p$ so that *p* is unaffected by the windfall. We thus see from (12) that a previously unanticipated windfall leads to an immediate and permanent reduction in the marginal value of wealth and immediate and permanent boost to consumption irrespective of capital intensity. We are thus back to the PIH.

intensive in structures, genuine saving is only zero if $\sigma = 1$. If $\sigma > 1$, the intertemporal substitution effect dominates the income effect so that total wealth $A + pS$ increases over time and it is optimal to put some of the windfall in a parking fund. The economy then contracts financial assets by less than is required for the accumulation of structures. If $\sigma < 1$, genuine savings will be negative and thus there will be more borrowing from abroad than is necessary to finance the structures.

With specific factors (or decreasing returns to scale in production in each sector) the results of Proposition 1 for the benchmark economy of section 2 must be modified. Although there will still be no adjustment dynamics and the change in consumption will still be given by (7), the real exchange rate p will increase after a windfall (see appendix 6), as higher demand for non-tradables encounters diminishing returns. With non-tradable structures these long run effects are associated with short run dynamics. If non-tradables are intensive in structures there is real exchange rate appreciation and overshooting, while consumption undershoots, as in proposition 2.[14]

4. Managing a Windfall with Irreversible Investment

The preceding section showed how 'home-grown' capital implies slow adjustment for an economy that has to accumulate or decumulate capital (structures). However, it retains the assumption that capital, although it cannot be traded internationally, can be unbolted and used for alternative purposes in the domestic economy. This understates the magnitude of the absorption constraint. For example, in the central case in which the two sectors have the same factor intensities, adjustment would be instantaneous as structures are simply redeployed from the tradable to the non-tradable sector.[15] In practice it is expensive, or perhaps impossible, to reallocate capital to alternative uses, and capital or structures can only be decumulated by being scrapped or gradually run down by wear and tear. A policy relevant model therefore needs to investigate the case in which investment decisions are irreversible; there are constraints not only in changing the aggregate stock of capital, but also its allocation between sectors.

Irreversibility requires keeping track of investment decisions and capital stocks in each sector separately. Additionally, we further generalize the model by allowing the capital stock of each sector to be made up of both equipment (traded) and structures (non-traded) goods.[16] Thus, capital in each sector, K^T, K^N consists of an aggregate of tradables and non-tradables, with unit cost functions $b^T(p)$, $b^N(p)$. These

[14] If the traded sector is structures intensive, the price of non-tradables now undershoots and real consumption no longer adjusts instantaneously but overshoots its new long run value.

[15] And in the case in which capital is decumulated, some structures are consumed.

[16] The share of non-tradables in capital is stable across time & countries and is in the range 0.54-0.62 (Bems, 2008).

functions can be different for each sector, and the elasticity of each with respect to *p*, $\beta^i \equiv pb_p^i(p)/b^i(p) < 1$, is the share of structures in the sector's capital aggregate. This generalizes and encompasses the previous models, since in the model of traded capital equipment in section 2 we have $b^T(p) = b^N(p) = 1$, while the model of non-traded structures of section 3 has $b^T(p) = b^N(p) = p$. The accumulation of the capital stocks of the traded and non-traded sectors is given by:

$$\text{(16)} \qquad \dot{K}^T = I^T - \delta^T K^T, \quad I^T \geq 0, \quad K^T(0) = K_0^T, \quad \dot{K}^N = I^N - \delta^N K^N, \quad I^N \geq 0, \quad K^N(0) = K_0^N,$$

where I^T and I^N denote investment, and rates of depreciation are δ^T, δ^N. The two non-negativity requirements imply that capital cannot be unbolted and put to another use.

The problem is to maximize social welfare (1) subject to (16), the current account dynamics (budget constraint) and the condition for equilibrium in the market for non-traded goods:

$$\text{(17)} \qquad \dot{A} = r^* A + Y(p, K^T, K^N) - e(p)C - b^T(p)I^T - b^N(p)I^N,$$

$$A(0) = A_0^F + V(0), \ \lim_{t\to\infty} e^{-r^*t}A(t) = 0,$$

$$\text{(18)} \qquad Y_p(p, K^T, K^N) = e_p(p)C + b_p^T(p)I^T + b_p^N(p)I^N,$$

where the GNP function now depends on sector specific sunk capital K^T and K^N (instead of *K* or *S* as in sections 2 and 3).

As before, the Keynes-Ramsey rule is (12). Optimal investment in the two sectors follows from the complimentary slackness conditions:

$$\text{(19)} \qquad \left.\begin{array}{c} I^T \geq 0 \\ PV^T \leq b^T(p) \end{array}\right\} \text{c.s.}, \quad \left.\begin{array}{c} I^N \geq 0 \\ PV^N \leq b^N(p) \end{array}\right\} \text{c.s.}, \quad PV^i(t) \equiv \int_t^\infty Y_{K^i}(p, K^T, K^N) e^{-(r^*+\delta^i)(s-t)} ds, \ i = T, N.$$

We thus see that if the present value of a unit of investment is less than its cost, no investment is undertaken. If a positive amount of investment is undertaken, the present value of the marginal profits on a unit of investment must equal its cost. In that case we have the investment arbitrage conditions:

$$\text{(20)} \qquad Y_{K^i}(p, K^T, K^N) = b^i(p)\left(r^* + \delta^i - \beta^i \frac{\dot{p}}{p}\right) \ \text{if} \ I^i > 0, \quad i = T, N, .$$

Hence, the marginal product of capital in each of the two sectors equals the user cost of capital consisting of the interest plus depreciation charges minus the capital gains on these capital goods. If investment is positive in each sector, the division of investment between sectors must be such as to make both arbitrage equations hold. If investment occurs only in one sector, it occurs in the sector with the highest return.

As before, we start from an initial stationary equilibrium, and the windfall is a positive shock to the economy's wealth. Now that capital is immobile between sectors it is quite generally the case that adjustment is slow and involves appreciation of the real exchange rate. Even if the capital intensity of the two sectors is the same, it is not possible to get an instantaneous jump in the supply of non-tradables by re-allocating capital. Instead, as consumption demand increases, so market clearing for non-tradables, equation (18), requires an increase in *p*. However, the form and drivers of this price change continue to depend on relative factor intensities. To draw this out we look at two polar cases, analogous to the two cases of section 3. The first assumes that there is no capital whatsoever in the traded sector, and the second that there is no capital in the non-traded sector. We then combine these for the central case in which capital intensities are the same in both sectors.

Capital used only in non-traded goods production: $K^N > 0, K^T = 0$

Since the traded sector only uses labour and has constant returns, the wage in terms of tradables is fixed. With positive investment in the non-traded sector only, the price of non-tradables follows from (20):

$$\dot{p} = \left[r^* + \delta^N - \frac{Y_{K^N}(p,0,K^N)}{b^N(p)} \right] \frac{p}{\beta^N}. \tag{21}$$

Accumulation of capital depends on supply of non-tradables so, using (16) in (18),

$$\dot{K}^N = \frac{Y_p(p,0,K^N) - e_p(p)[e(p)\lambda]^{-\sigma}}{b_P^N(p)} - \delta K^N, \qquad K^N(0) = K_0^N. \tag{22}$$

The model (21)-(22) is qualitatively equivalent to case (a) of proposition 2 of section 3 (see (14), (15) with $Y_{SS} = 0, Y_{pS} > 0$, whereas now $Y_{K^N K^N} = 0$ and $Y_{pK^N} > 0$). A windfall thus leads to temporary appreciation of the real exchange rate whilst the stock of capital in the non-traded sector grows to its new long run value (cf. panel (a) in Figure 1 with *S* replaced by K^N). Real consumption undershoots whilst consumer spending, $eC = e(p)^{1-\sigma}\lambda^{-\sigma}$, overshoots (undershoots) its long run value if the elasticity of intertemporal substitution σ is less (greater) than one.

Quantitative behaviour depends on the share of non-tradables (structures) in capital, as captured in the cost function $b^N(p)$. This can be drawn out explicitly, and is easiest to do with the restriction that structures and equipment are used with fixed coefficients, so $b^N(p) = \tilde{\beta}p + 1 - \tilde{\beta}$, where $\tilde{\beta}$ is the input of structures (non-tradables) per unit output and $1-\tilde{\beta}$ is the input of equipment (tradables with price 1). The (local) time paths of K^N and p are then given by (see appendix 7):

(23) $$K^N(t) = K_0^N + \Delta K^N\left[1-\exp(-t\xi)\right],$$

(24) $$p = \bar{p} + \left(\frac{2Y_{pK^N} - \tilde{\beta}(2\delta^N + r^*)}{Z_p}\right)\Delta K^N \exp(-t\xi)\,,$$

where the adjustment speed is $\xi = (Y_{pK^N}/\tilde{\beta}) - \delta^N - r^* > 0$. $Z_p > 0$ is the slope of the supply of non-tradables available for use in investment, $Z(p,K^N,\lambda) \equiv Y_p(p,0,K^N) - e_p(p)[e(p)\lambda]^{-\sigma}$, and the term in the round brackets in (24) is positive. The input of structures per unit capital, $\tilde{\beta}$, is crucial for the comparative dynamics. The lower is this coefficient, the faster is the adjustment speed ξ. If $\tilde{\beta} = 0$ then adjustment is instantaneous, as in section 2; an economy which can import all its capital goods jumps directly to the new equilibrium. However, while lower $\tilde{\beta}$ gives faster adjustment it also means a *larger* price jump on impact for a given λ. Essentially, with lower $\tilde{\beta}$ it becomes efficient to ramp up investment more rapidly. Since investment goods use non-tradables, there has to be a large increase in their price to accommodate this investment demand. The size of the initial price jump also depends on the responsiveness of net supply of non-tradables to prices; the greater this responsiveness (larger Z_p), the smaller the price jump. Adjustment is faster the lower are the rates of depreciation and interest, and the more sensitive is production of non-tradables to the capital stock (higher Y_{pK^N}).

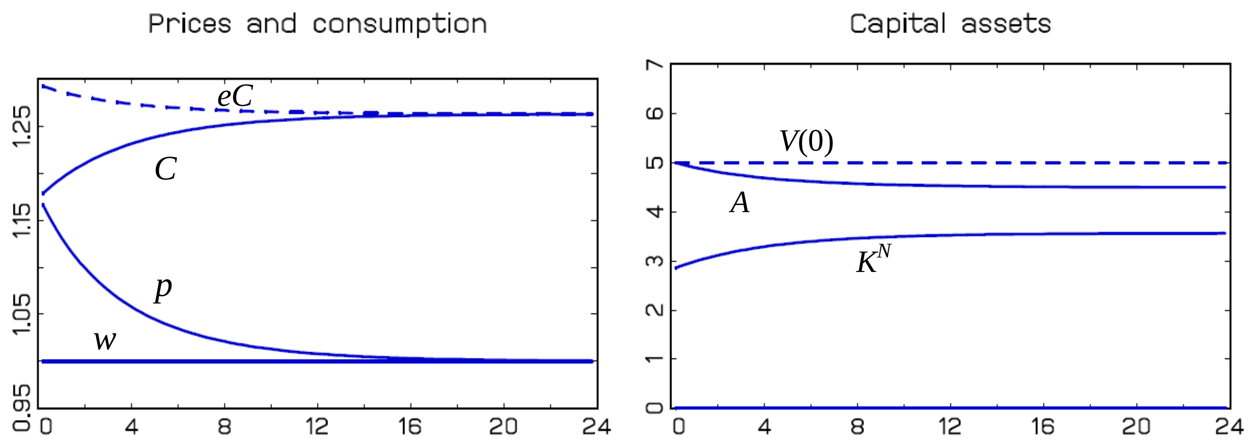
The dynamic path is illustrated in panel (a) of Figure 2. This and following figures set the rate of time preference and the world interest rate at 5% and time periods (horizontal axis) can be loosely interpreted as years. The intertemporal elasticity of substitution is σ = 0.75, and the expenditure function is Cobb-Douglas with non-tradable share, θ^C = 0.6. Technologies are Cobb-Douglas, with the share of non-tradables in capital goods, β^i = 0.75 for $i = N, T$. In panel (a), the shares of capital in production of non-tradables and tradables are set at 0.4 and zero respectively.

The experiment reported is a windfall with annuity value equal to 25% of initial consumption, i.e, a capital value of 5 times initial consumption (at interest rate of 5%). The vertical axis of the left hand panel gives values relative to their initial value. There is an initial jump in consumption of 16%, followed by convergence to its new higher value. The real exchange rate, p, jumps by 15% on impact and then falls back to its initial value. Since $\sigma < 1$ consumption expenditure, eC, overshoots.

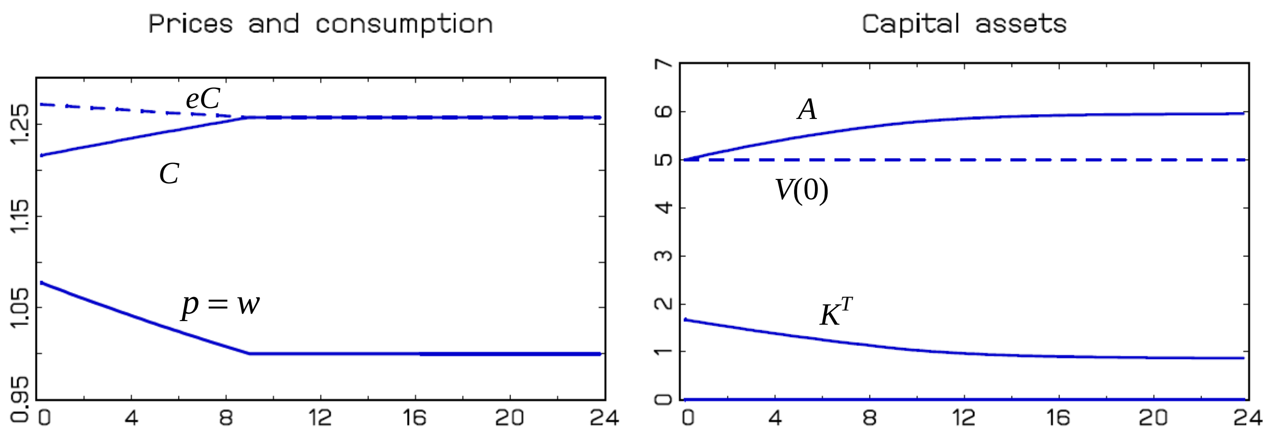
The right hand panel gives the evolution of assets (expressed relative to initial consumption). The horizontal dashed line is the value of the windfall at the date it occurs, $V(0)$, and A is the sum of financial assets and resource wealth, $A \equiv A^F + V$. A falls to finance the increase in K, as we saw in section 2, although the decline is now slow. The division of A between A^F and V depends on the time paths of N and hence V. For example, if the windfall is continued at a constant rate N in perpetuity so that V is constant at $V = N/r^*$, then as A falls so the economy runs a (non-resource) current account deficit and foreign debt $A^F < 0$ is acquired to finance physical capital accumulation. Notice, however that the debt increases slowly through time, converging to a constant level.

Figure 2: Irreversible investment: unequal capital intensities

(a) Capital used only in non-traded goods production: $K^N > 0, K^T = 0$



(b) Capital used only in traded goods production: $K^T > 0, K^N = 0$



Capital used only in traded goods production: $K^T > 0, K^N = 0$

If capital is used only in the contracting traded-goods sector, then adjustment requires decumulation of capital and transfer of labour to non-tradables. With irreversible investment capital decumulation takes place only through depreciation. This slows the transfer of labour to non-tradable production, so that the increase in demand for non-tradables causes an upwards jump in their price and in the wage.

Formally, non-tradables are now produced by labour alone, and labour input per unit non-tradable output is denoted a^N. This means that the wage is proportional to the real exchange rate, $p = wa^N$. The system now has differential equations for p and K^T:

(25) $$\dot{p} = \left[r^* + \delta^N - \frac{Y_{K^T}(p, K^T, 0)}{b^T(p)} \right] \frac{p}{\beta^T} \quad \text{if } I^T > 0,$$

(26) $$\dot{K}^T = \frac{Y_p(p, K^T, 0) - e_p(p)[e(p)\lambda]^{-\sigma}}{b_P^T(p)} - \delta K^T, \qquad K^T(0) = K_0^T.$$

Response to the windfall takes place through two phases. In the first $I^T = 0$, so equation (25) does not hold and the capital stock depreciates according to $\dot{K}^T = -\delta^T K^T$. Hence, non-traded goods market clearing (equation (26)) gives $Y_p(p, K^T, 0) = e_p(p)\left[e(p)\lambda\right]^{-\sigma}$, and p solves this equation. On impact therefore, the reduction in λ leads to an increase in demand for non-tradables and hence an increase in p and w. Afterwards, p and w gradually fall back as K^T depreciates, more labour is released for the non-tradable sector and supply of non-tradables expands. When p and w reach the long run equilibrium level investment starts.[17] In this second phase prices and wages are constant, so equation (26) is a single differential equation in K^T which converges asymptotically to its new steady state value.

Panel (b) of Figure 2 illustrates this equilibrium path (now with the share of capital in non-tradables equal to zero and in tradables equal to 0.4). The behaviour of real consumption and the real exchange rate is similar to that in panel (a), but the mechanism is quite different. Both p and w jump up to secure the transfer of labour from the tradable sector to the non-tradable. In the first phase there is no investment, $I^T = 0$, and the economy runs down its capital stock. As a consequence the economy builds up capital assets in excess of the windfall, running a current account surplus which leads to a terminal stock of assets, A, greater than the value of the windfall.

[17] In the first phase the right-hand side of (25) is positive and declining, and the left hand side is negative. The present value of investment is therefore negative until new long run equilibrium prices are reached.

Capital used in both sectors: $K^N > 0, K^T > 0, \quad \beta^N = \beta^T > 0$

We now allow both sectors to use capital and focus on the central case in which they have the same technologies with, for numerical purposes, the capital share in production set at 40% and share of non-tradables in capital set at $\beta^i = 0.75$. This symmetry means that there is no long run change in the economy's total physical capital stock, $\Delta K^N + \Delta K^T = 0$.[18] The dynamic system is now the full set of equations (16)–(19). The adjustment of the economy is illustrated in Figure 3 and combines effects from the previous two subsections.

First, there is a jump then a slow increase in consumption, *C*. The price of non-tradables and the wage both jump up on impact, but *p* increases by more than does *w*. This is because the release of labour from the tradable sector requires an increase in *w*, while capital accumulation in non-tradables requires an increase in *p/w*. As in previous cases, the price path and associated path of *e*(*p*) means that it is efficient for some of the adjustment of consumption to be delayed.

Second, there is a steady increase in the capital stock in the non-tradeable sector, K^N, (I^N jumps upwards, then increase further for a period). Investment in tradables ceases (for some 12 time periods) and the capital stock K^T depreciates. The long run structural change in the economy increases the share of non-tradeables in production (and in employment and capital) from 63% to 75%.

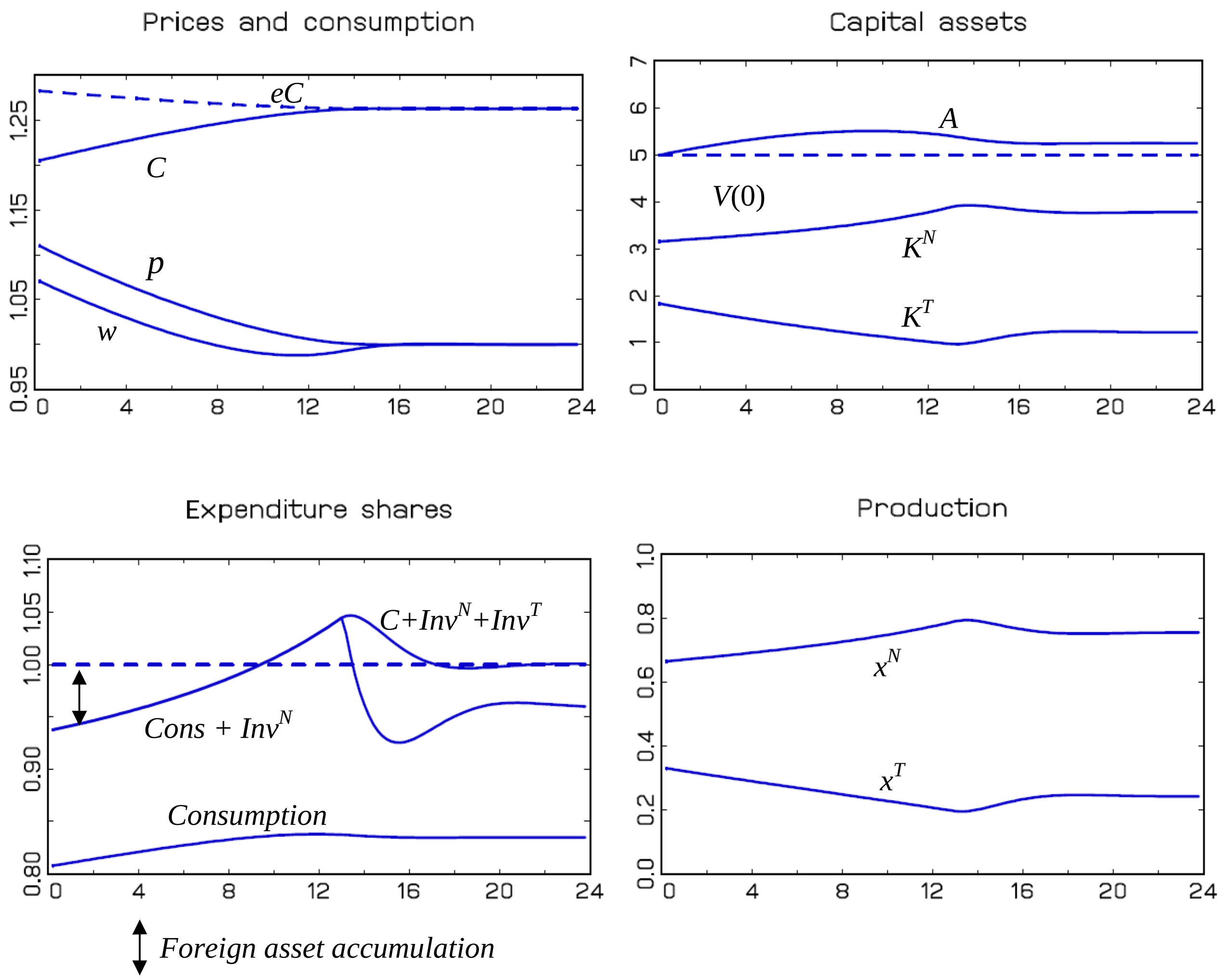
Third, in the early years of adjustment the economy builds up assets *A* (top right panel). This is easiest to interpret for the case in which *N* is constant in perpetuity and so therefore is *V*. The economy then runs a payments surplus and builds up foreign assets, A^F. The bottom left panel gives expenditure shares in GNP (inclusive of *N*). Expenditure in the domestic economy (consumption and capital investment) is less than income because of the bottleneck created by lack of non-traded capacity, so it is efficient to 'park' funds offshore. Once the constraint is relaxed it becomes efficient to draw down these funds, and total domestic spending and investment peaks around year 13. A corollary of this time profile of asset accumulation/ spending is that the share of non-tradable production overshoots (bottom right panel).

Comparative dynamic analysis indicates that these results are qualitatively robust. The preceding sub-sections indicate how results depend on the capital intensities of the expanding and contracting sectors. Reducing the share of non-traded goods in investment means that adjustment is faster (becoming, in the limit, instantaneous), although the price jump is larger and initial jump in consumption smaller, in line

[18] The labour force is fixed and capital labour ratios are, in the long run, unchanged.

with the analytical result derived above (equations (25) and (26)). Moving from Cobb-Douglas technologies to CES with a lower elasticity of substitution increases price effects, as we will see below.

Figure 3: Irreversible investment: Identical technology both sectors



The costs of absorption and benefits of optimal policy

Structural change requires redeployment of resources – in the example above, there is a one-off reallocation of 12% of the labour force and capital stock from the tradable to the non-tradable sector. How costly is this? Table 1 gives the numbers corresponding to figure 3, together with some further experiments.

The first row gives the frictionless PIH outcome. The windfall (with annuity value 25% of initial consumption and capital value 5 times consumption) causes immediate adjustment and no welfare cost is attributable to absorption frictions. The second row of the table ('optimal') gives outcomes corresponding to figure 3, reporting the changes in C and A (relative to initial consumption) and price changes. As described above, there is an initial jump in consumption, followed by a rise to a level greater than what would have been achieved under the frictionless PIH, because additional assets have been accumulated along the path (long run $\Delta A = 5.25 > V(0)$). The first column reports the welfare cost of absorptive capacity constraints. This is measured as the present value of utility (equation (1)) minus the present value of utility in the frictionless PIH case, expressed relative to utility from first period consumption $U(C_0)$.[19] This is the one-off cost of implementing structural change, and we see that it amounts to 1.1% of initial utility. This seems small, but recall that it is the cost of a one-off reallocation of 12% of GDP in an economy without distortions. The next two rows give the effect of non-optimal policy. One interpretation of a naive PIH would to hold real consumption, C, constant. The attainable level of consumption is obviously less than in the frictionless world, and causes large price changes and pushes investment off its optimal path; it increases the cost of absorption to 1.7% of base period utility. An alternative policy would be to hold A constant, maintaining the value of the resource plus financial assets. This is more damaging; expenditure increases too fast giving even larger price swings, and a total welfare cost of 2.5% of base utility.

Table 1: Costs of adjustment

	Welfare cost, % initial utility	Jump in C	Long run ΔC	Long run ΔA	Δp	Δw	Convergence time
Frictionless PIH	0%	25.0%	25.0%	5.0	0	0	0
$\beta^N = \beta^T = 0.75$, Cobb-Douglas: elasticity of substitution = 1							
Optimal	1.1%	20.5%	26.3%	5.25	11.0%	7.03%	≈ 14
C = constant	1.7%	24.65%	24.65%	4.93	13.7%	8.8%	≈ 17
A = constant	2.5%	31.5%	25%	5.00	19.2%	12.6%	≈ 16
$\beta^N = \beta^T = 0.75$, CES: elasticity of substitution = 0.15							
Optimal	2.6%	16.1%	27.0%	5.40	22.1%	12.6%	≈ 15
C = constant	3.0%	24.4%	24.4%	4.90	36.0%	20.0%	≈ 17
A = constant	3.6%	27.7%	24.7%	5.00	42.0%	22.4%	≈ 16

[19] Since this is a one-off change, we express it relative to one 'year' of utility, where the length of a year is set by having the interest rate at 5% per year.

These numbers are modest, although this is partly because, with Cobb-Douglas technologies, it is relatively easy to substitute tradable for non-tradable goods in the capital stock (function $b^i(p)$) and to substitute labour for capital in each sector's production function. The bottom block of Table 1 repeats calculations with all parts of the technology made CES with elasticity of substitution 0.15. This rigidity approximately doubles the price movements and welfare costs associated with absorption.

Imperfect capital mobility and capital scarcity

Up to this point the direct impact of the windfall has been on income and hence consumer demand. This is in keeping with the classic analysis of the Dutch disease, but ignores other impacts that might be important in developing countries. For example, the windfall might relax constraints on the supply of capital for domestic production, or on the supply of public funds for government. It will then have the effect of increasing domestic investment and bringing forward the growth path of the economy. Van der Ploeg and Venables (2011) develop this argument, but abstract from the absorption issues which are the focus of this paper.

To combine absorption effects with a capital market imperfection, we now assume that the domestic production sector initially has to pay an interest premium $\hat{r}$, so faces interest rate $r^* + \hat{r}$. As a consequence the capital stock, wages, and consumption are initially lower than they otherwise would have been. We do not model $\hat{r}$ endogenously, but merely suppose that the windfall has the effect of reducing $\hat{r}$, this being unanticipated, occurring at the date of the windfall, and lasting in perpetuity. The economy now faces an investment boom due to this reduction in the cost of capital to firms, in addition to that arising from structural change associated with higher consumption.[20]

The structures model of section 3 is easily modified to capture this extension. Dynamics are given by equations (14) and (15), with (15) modified to include the initial interest premium, as in (15′),

(15')
$$\dot{p} = \left[r^* + \delta^N + \hat{r} - Y_S(p,S)\right]p\,.$$

Figure 4 reproduces the phase diagram for the case in which the non-traded good is intensive in structures (Figure 1a), but now the windfall has two effects. The *S* stationary shifts as before (moving the long run equilibrium from E_0 to E_∞) and the *p* stationary now shifts down, giving new long run equilibrium at E_+.[21] The intuition is that the more capital intensive good is relatively expensive in the initial situation, and

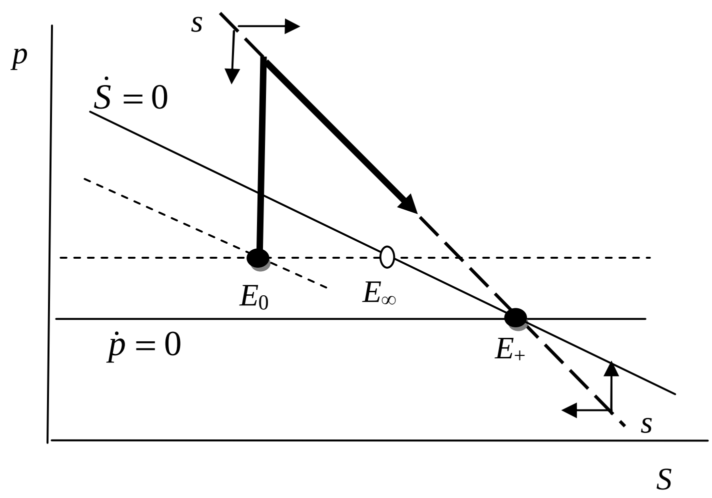
[20] An investment boom might also be due to the direct costs of resource extraction (the resource movement effect of Corden and Neary (1982)), but we abstract from this. We continue to assume that consumers face $r^* = \rho$.

[21] Down in the case in which the non-traded goods sector is capital intensive ($Y_{pS} > 0$) and up in the converse case.

becomes cheaper in the new stationary state (E_+) once the cost of capital is reduced. As expected, the quantity of capital is also larger at E_+ than at E_∞. Dynamics are illustrated by the new saddlepath going through E_+. The initial jump in *p* is larger, although it converges to a lower level. Correspondingly, the initial jump in consumption is smaller.

Figure 4: **Dynamic effects of a windfall and removal of capital market imperfection**

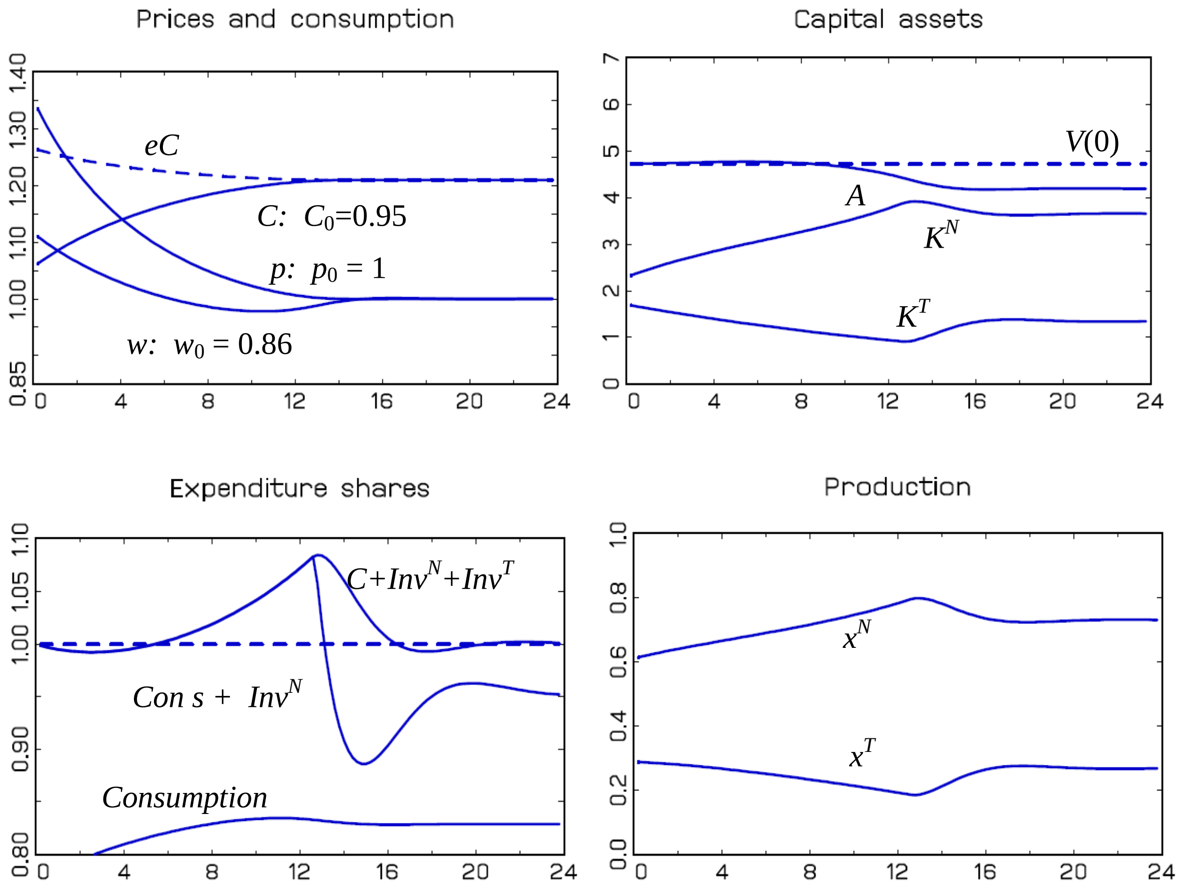
Non-traded good sector intensive in structures: $Y_{pS} > \delta$



For the case in which investment is irreversible effects are illustrated on Figure 5. This is constructed for the same economy as Figure 3, except that the domestic production sector initially faces an interest rate of 7.5%, which drops to 5% on impact. The higher interest rate depresses initial capital stocks, wages and consumption (but has no effect on the relative price *p*, since in this example both sectors have the same technology). The windfall causes a larger response of domestic investment, in both the short and the long run, and this in turn leads to larger price effects (an initial jump in *p* (of 35%) and in *w* (30%)). Long run consumption increases more because of the efficiency gain, but the short run jump in consumption is relatively small as it is efficient to reduce consumption to accommodate the larger increase in investment (compare the consumption shares of expenditure, lower left panel figures 3 and 5). Funding the higher level of investment means that less revenue is placed in foreign assets, in both the short and the long run (top left, bottom right panels).

In summary, adding the possibility that the windfall has a direct effect on investment by bringing down the cost of capital faced by domestic production, brings an additional source of real income gain, and amplifies the absorption issues on which we focus.

Figure 5: Expenditure and investment effects



5. Comparison and qualification of results

We now compare our results to the earlier literature on Dutch disease and qualify them by pointing at the required extensions of our framework before proceeding to practical policy formulation.

Static models of Dutch disease

The classic static model of Dutch disease is that of Corden and Neary (1982), and a number of authors have extended their results in the context of static two-sector Heckscher-Ohlin models of a small open economy. For example, Hamilton and Hartwick (2009) study an economy which does not have access to international capital markets and exports a tradable good to finance an imported capital good. They too find that the traditional export sector declines whilst the local goods sector expands following a resource discovery. They show that, if there is a specific fixed factor, say land, and its factor share is large enough, imports of capital can steadily decline as oil earnings expand.[22] Ismail (2010, section III) also studies a static two-sector model of Dutch disease and finds that, if non-tradables are labour-intensive and capital is immobile, Dutch disease raises wages relative to rent which in turn has a stronger impact on labour-intensive industries than capital-intensive ones. Furthermore, if labour is immobile, capital mobility may result in cushioning or amplifying the Dutch disease depending on whether non-tradables are capital or labour intensive. With capital mobility and no specific fixed factors the windfall does not affect the real exchange rate or the wage. The evidence provided by Ismail (2010) indeed suggests that manufacturers in oil-exporting countries with more open capital markets have been more negatively impacted by oil price shocks than in similar counties with less open capital markets.

If the natural resource sector requires labour and capital to start exploration, the appreciation of the real exchange rate causes de-industrialization as before but in addition production factors will be drawn out of both the non-traded and traded sectors towards the resource sector. The impact of this depends on the relative factor intensities of different sectors and the mobility of factors between sectors, and could offset or amplify the spending effects (Corden and Neary, 1982). For example, real exchange depreciation may result from a boost to natural resource exports if the traded sector is relatively capital intensive and capital is needed for the exploitation of natural resources (Neary and Purvis, 1982). Since less capital is available for the traded sector, less labour is needed and thus more labour is available for the non-traded sector. This may lead to a depreciation of the real exchange rate. This also occurs if the income distribution is shifted to consumers with a low propensity to consume non-traded goods (Corden, 1984).

Our analysis differs from these earlier studies principally because of our dynamic setting. We also draw out the roles of non-traded capital equipment and irreversibility of investment decisions, these features giving rise to our dynamic story of Dutch disease and absorption constraints. While we have assumed that the windfall (i.e. the natural resource sector) does not directly require inputs, it would be straightforward to extend our framework to add this. We conjecture that the effects would be similar to the investment boom triggered by a reduction in the user cost of capital (section 4). Higher domestic expenditure would cause larger price swings and cause less resource revenue to be parked offshore (and would perhaps require foreign borrowing) to finance the spending.

Sectoral adjustment costs

Moshed and Turnovsky (2004) study the effects of a resource boom in a dynamic dependent economy with adjustment costs for investment and allow for costly sectoral reallocation of capital between non-traded and traded sectors. They thus allow for factor specificity for each sector in the short run and factor

[22] Earnings from oil sales are stationary under their annuitization construction.

mobility across sectors in the long run. Hence, in the short and medium run the real exchange rate is no longer fully determined by the supply side and does not adjust instantaneously. If a greater fraction of resource revenues is saved, the initial appreciation of the real exchange rate will be less and is eventually reversed. One could also use a model of endogenous growth in the dependent economy (e.g. Turnovsky, 2009) to explore the implications of a resource boom on economic growth. In contrast to this line of research, we have considered the polar case where capital is completely sector specific whilst labour can move between sectors. Allowing for convex sectoral adjustment costs would not alter our insights in a fundamental way, but would allow us to trace out a continuum of models varying from full sectoral mobility to complete immobility of capital.

Learning by doing and dynamics of Dutch disease

A shrinking traded sector is the appropriate market response to a resource windfall. In itself this does not justify government intervention and strictly speaking does not warrant the term 'disease'. Why are resource windfalls then perceived to be a problem? One answer is that the traded sector benefits most from learning-by-doing externalities. Hence, non-resource export sectors temporarily hit by worsening competitiveness are unable to fully recover when resources run out (van Wijnbergen 1984; Krugman, 1987). Similarly, if human capital spill-over effects in production are generated largely in the traded sector, natural resource exports which lower employment in this sector hamper learning by doing and reduce technical progress and economic growth (Sachs and Warner, 1997; Torvik, 2001). With perfect international capital mobility and no specific factors of production, the wage, the relative price of non-traded goods and the capital intensities in the traded and non-traded sectors are pinned down by the world interest rate. Still, a temporary resource boom induces gradual movement of labour from the traded to the non-traded sector and permanently lowers the rate of growth.[23]

The empirical literature on the resource curse suggests that resource rich countries with relatively poor institutions, trade restrictions and little financial development suffer worse growth prospects even after controlling for conventional determinants such as initial income per capita, saving, education, openness, institutional quality and population growth (Sachs and Warner, 1997; van der Ploeg, 2011).

The models we have put forward in sections 2-4 concentrate on the interactions between Dutch disease and absorption constraints, and abstract from learning-by-doing externalities. They thus have no market failure and no role for temporary export subsidies. However, it is easy to extend our framework to allow

[23] The decline in relative productivity of the traded sector induces gradual depreciations of the real exchange rate and falls in labour use in the non-traded sector. In the end this fully chokes off the initial expansion of the non-traded sector and eliminates the boom of the traded sector. Production has moved in favour of the non-traded sector, not due to reallocation of labour, but due to the relative fall in productivity of the traded sector (Torvik, 2001).

for contraction of the rate of endogenous growth when the traded sector contracts. Our main insights that structures are home grown and that the resulting absorption constraints make the optimal policies depart from the usual permanent-income recommendations are unaltered.

Public sector inefficiency and calibration of intertemporal absorption constraints

Berg et al. (2011) provides a complimentary analysis of a fully specified, calibrated, discrete-time DSGE model with a tradable, non-tradeable and resource sector where the cost of public investment increases in the rate of investment. An alternative is to have an internal cost of adjustment approach for structures in combination with an imperfect capital market as in van der Ploeg (2012). The cost of adjustment parameter is then calibrated from recent public investment measures of inefficiency, which indicate that for many developing countries a mere 40 percent of investment spending actually leads to augmentation of structures (Dabla-Norris et al., 2011; Gupta, et al., 2011). Both approaches capture *intertemporal* absorption constraints rather than the *intratemporal* constraints emphasized in our framework of sections 2-4. They both imply that ramping up public investment financed by revenue from a resource bonanza will lead to a deterioration of the efficiency of public investment. It is therefore optimal to slow down the accumulation of structures to avoid too large inefficiencies. To the extent that this occurs, this gives an additional reason to put some of the windfall revenue in a parking fund.

Uncertainty about future commodity prices and reserves discoveries

Typically, resource windfalls are highly uncertain due to the notorious volatility of commodity prices. Oil and other commodity prices are hard to distinguish from random walks and have a large degree of persistence. Given the political unattractiveness of hedging commodity price risk, the best response might be to accumulate precautionary buffers into a liquidity fund and save more than is necessary to smooth across different generations with certain windfalls and thus to have bigger surpluses on the current account (Bems and de Carvalho Filho, 2011; van den Bremer and van der Ploeg, 2012). The size of the *liquidity* fund is bigger if future shocks to commodity prices are more volatile and persistent and the policy maker is more prudent. The saving needed to smooth consumption across generations would be accumulated in an *intergenerational* fund and the funds necessary to fund domestic investment when absorption constraints are alleviated would be accumulated in a *parking* fund. It may also be prudent to deplete reserves less aggressively if future reserves and discoveries are highly uncertain, because things may always turn out worse than expected. A country may also save more for prudential reasons if future income growth and thus the future tax base is highly volatile. We have not taken account of uncertainty in the framework put forward in sections 2-4, but any practical study towards the required savings response would have to take account of uncertainty and prudence.

6. Conclusions and policy implications.

Economies faced by shifts in their endowments, technology, preferences, or the world prices that they face, cannot generally jump to a new equilibrium. Supply curves are not perfectly elastic and investment is required to make the adjustment. In turn, investment goods (both structures and human skills) are partly non-tradable, so take time to accumulate. This paper explores the implications of these observations in the context of a natural resource windfall. The windfall could arise from an increase in resource prices, although the main context we have in mind is the newly resource rich countries of the developing world.[24]

We analyse the implications of capital goods having a non-traded element (i.e. being comprised of structures and skills as well as equipment), and of sectoral immobility of capital. Both constrain the speed at which the economy can adjust so that a windfall leads to a short run increase in the price of non-tradables (real exchange appreciation) that then unwinds as the economy adjusts. If capital is sectorally mobile this arises if the non-traded sector is relatively capital intensive. With sectoral immobility of capital this behaviour is quite general.

How do these constraints and consequent price behaviour shape policy towards resource revenue management? First, efficiency requires a rapid build up of investment in the non-tradable sector. The price of non-tradables jumps up at the date of discovery; this raises the rate of return in the sector, and the efficient (and equilibrium) path involves their price then falling back as supply expands. Second, there is a long run increment to consumption but consumption should only jump partway on impact, and then continue to rise towards the long run value. It is efficient to postpone the full increment to consumption, since part of consumption is non-traded goods which are relatively expensive due to the Dutch disease price effects. Domestic spending as a whole does not jump the whole way to its new steady state level, because of these intertemporal substitution effects.

Foreign asset accumulation is shaped to accommodate the efficient paths of investment and consumption in the domestic economy. In the benchmark case of the simple permanent income hypothesis the increment to consumption is equal to the annuity value of the windfall, and is sustained by building an offshore fund of value equal to the windfall. Our recommendations differ from this in two respects. First, structural change has long run financing needs; if the non-tradable sector is relatively capital intensive some fraction of resource revenues will need to be used to finance its expansion (rather than being held

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[24] Since 2004 there have been oil and gas discoveries in Chad, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Mali, Mauritania, Mozambique, Sao Tome Principe, Senegal, Sierra Leone, Tanzania, Togo and Uganda. There is also development of coal in Mozambique and other minerals, particularly iron ore, in a number of SSA countries.

offshore). Second, the slow build up of domestic spending means that resource revenues should be 'parked' in an offshore fund until it is efficient to spend them domestically; the time profile of this fund depends on the precise timing of the revenue flow, but may suggest running a current account surplus in early years followed by a deficit as investment in the domestic economy reaches its peak. These points caution against equating saving out of a windfall with accumulation of foreign assets.

Several further implications follow from the analysis. In capital scarce economies policy requires investment principally in the domestic economy rather than in foreign assets (van der Ploeg and Venables 2011). However, the impact of this on domestic spending amplifies the price effects described above. This alters the policy recommendations of the earlier paper in two ways. First, there should be a slower build up of consumption; this is efficient, given the relative price change, and serves to accommodate rising domestic investment. Second, since the rate of increase of domestic investment must also be optimised against this price path; once again, this creates a case for 'parking' funds offshore until absorption constraints are relaxed, even if the long-run outcome is to invest all in the domestic economy.

While our analysis has focussed on constraints created by the underlying technology of the production and use of capital goods, other governmental, administrative, and policy constraints will also be present. Much of the non-traded capital required is publically provided capital in the form of road and transport structures, electric power and other utilities, and worker training and human capital. Delivery of these will require building up government capacity for project selection and implementation, as highlighted by recent work on the efficiency of public investment management (e.g. Gupta et al, 2011; Dabla-Norris et al., 2011).[25] Private sector supply response can be promoted by being open to trade and by removing barriers to entry and other rigidities in the business environment. If resource revenues are to be spent effectively it is important that government anticipates the boom associated with resource discovery and addresses the bottlenecks that are likely to be encountered. All of this has been referred to as a process of 'investing-in-investing' (Collier 2010), capturing the fact that the structural adjustment associated with a windfall requires home-grown private, public, and skills capital.

[25] It also requires a political preparedness, in the form of transparent revenue management institutions to reduce the likelihood of theft of funds, or of diversion of revenue into inefficient partisan projects.

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Appendix

1. The GNP functions

Under constant returns to scale unit cost equals price, i.e. $a^T(r,w) = 1$, $a^N(r,w) = p$, where the functions *a* are unit cost functions, *w* is the wage, and *r* the return on capital (net of depreciation). Given a value of *r* and both sectors in operation, these equations determine *p* and *w*. Factor prices and choices of technique are thus independent of factor endowments. Output levels in each sector adjust so that the first equation below holds, and price satisfy the second (cost functions are homogenous of degree one in prices):

$$\begin{bmatrix} a_w^N(r,w) & a_w^T(r,w) \\ a_r^N(r,w) & a_r^T(r,w) \end{bmatrix}\begin{bmatrix} X^N \\ X^T \end{bmatrix} = \begin{bmatrix} L \\ K \end{bmatrix}, \qquad \begin{bmatrix} a_w^N(r,w) & a_r^N(r,w) \\ a_w^T(r,w) & a_r^T(r,w) \end{bmatrix}\begin{bmatrix} w \\ r \end{bmatrix} = \begin{bmatrix} p \\ 1 \end{bmatrix}$$

Routine calculation gives: $X^N = \dfrac{a_r^T L - a_w^T K}{a_w^N a_r^T - a_r^N a_w^T}$, $X^T = \dfrac{a_w^N K - a_r^N L}{a_w^N a_r^T - a_r^N a_w^T}$, $r = \dfrac{a_w^N - a_w^T p}{a_w^N a_r^T - a_r^N a_w^T}$.

GDP is $Y(p,K) = pX^N + X^T = \left[\left(pa_r^T - a_r^N\right)L + \left(a_w^N - pa_w^T\right)K\right]\dfrac{1}{a_w^N a_r^T - a_r^N a_w^T}$.

From which, we obtain:

$$Y_p(p,K) = X^N = \frac{a_r^T L - a_w^T K}{a_w^N a_r^T - a_r^N a_w^T}, \qquad Y_{pK}(p,K) = \frac{-a_w^T}{a_w^N a_r^T - a_r^N a_w^T}$$

$$Y_K(p,K) = r = \frac{a_w^N - pa_w^T}{a_w^N a_r^T - a_r^N a_w^T}, \qquad Y_{KK}(p,K) = 0.$$

Notice that, from the sign of the determinant, $Y_{pK}(p,K) > 0$ if non-traded goods are capital intensive, negative otherwise (Rybczynski and Stolper-Samuelson theorems). The more similar are factor intensities, the larger the absolute value of $Y_{pK}(p,K)$, with singularity when the two sectors have the same intensities. We offer two examples of GNP functions.

Example 1: Let $X^N = L - L^T$ and $X^T = K^\alpha (L^T)^{1-\alpha}$, where L, L^T and $0 < \alpha < 1$ indicate employment in non-tradables production and the capital share in production of tradables, respectively. Profit maximization requires wage equalization across the sectors, so $w = p = (1-\alpha)(K / L^T)^{\alpha}$. Hence,

$Y(p,K,L) = pL + rK$ with $r = \alpha\left(\dfrac{1-\alpha}{p}\right)^{\frac{1-\alpha}{\alpha}}$. Production of tradables is capital intensive, so $Y_{pK} < 0$.

Example 2: Let $X^N = K^{\alpha}(L-L^T)^{1-\alpha}$ and $X^T = L^T$. Wage equalization across sectors implies $w = p(1-\alpha)[K/(L-L^T)]^{\alpha} = 1$. Hence, $Y(p,K,L) = L + rK$ with $r = \alpha(1-\alpha)^{\frac{1-\alpha}{\alpha}} p^{\frac{1}{\alpha}}$. Since non-tradables are capital intensive, $Y_{pK} > 0$. Note that $Y_{KK} = 0$ in both these examples.

2. Optimization conditions (section 2)

The Hamiltonian function for maximizing (1) subject to (2″) and (3) is defined as:

$H \equiv U(C) + \lambda\left[r^{*}A + Y(p,K) - e(p)C - \delta K\right] + \mu\left[e_p(p)C - Y_p(p,K)\right],$ where μ is the Lagrange multiplier for constraint (3). The optimality condition with respect to p is $\partial H / \partial p = \left[Y_p(p,K) - e_p(p)C\right]\lambda + \mu\left[e_{pp}(p)C - Y_{pp}(p,K)\right] = 0$ which given (3) implies $\mu = 0$. The optimality condition for A is $\rho\lambda - \dot{\lambda} = \partial H / \partial A = r^{*}\lambda$ which gives $\dot{\lambda}/\lambda = \rho - r^{*}$. Equation (5) then follows from differentiating the optimality condition $\partial H / \partial C = U'(C) - e(p)\lambda = 0$. Finally, $\rho\lambda - \dot{\lambda} = \partial H / \partial K = \lambda\left[Y_K(p,K) - \delta\right] - \mu Y_{pK}(p,K)$ then gives (6). We consider the case $r^{*} = \rho$ so $\dot{\lambda} = 0$.

3. Marginal value of wealth (section 3)

We follow section 3.2 and use $C = \left[e(p)\lambda\right]^{-\sigma}$ and solve (16)-(19) in terms of the constant marginal social value of wealth λ which jumps down at the time the windfall $N^P > 0$ becomes known. The size of this jump can be found from the economy's present value budget constraint:

$$\lambda = \left(\frac{r^{*}\int_0^{\infty} e(t)^{1-\sigma} e^{-r^{*}t}dt}{r^{*}\left[A_0 + V(0)\right] + r^{*}\int_0^{\infty}\left[Y(t) - b^T(t)I^T(t) - b^N(t)I^N(t)\right]e^{-r^{*}t}dt} \right)^{\frac{1}{\sigma}}.$$

4. Winding down structures without capital in non-tradables sector (section 3)

The qualitative dynamics are very different if the traded sector is structures intensive, $Y_{pS} < 0$.[26] If no capital is used in the non-traded sector, $p(t) = \bar{p}, \forall t \geq 0$. We also have $\dot{\lambda} = 0$ and $\dot{C} = 0$. From (10′), we get $e(\bar{p})C = r^{*}\left[A_0 + V(0)\right] + r^{*}\int_0^{\infty} Y(\bar{p},S)e^{-r^{*}t}dt.$ Upon substitution into (11), we get $\dot{S}(t) = Y_p(\bar{p}) - (\theta^C/\bar{p})\left[r^{*}\left[A_0 + V(0)\right] + w(\bar{p})L + r^{*}r^{S}(\bar{p})\int_0^{\infty} S(t)e^{-r^{*}t}dt\right] - \xi S(t),$ where we have used

[26] Cases (a) and (b) also occur in the literature on growth models of dependent economies (e.g., Turnovsky, 2009).

$Y(\overline{p},S)=w(\overline{p})L+r^{S}(\overline{p})S.$ By differentiating this equation, we get

$\ddot{S}(t)=\left[r^{S'}(\overline{p})-\xi\right]\dot{S}(t)-(\theta/\overline{p})r^{*}r^{S}(\overline{p})\left(r^{*}\int_{t}^{\infty}S(s)e^{-r^{*}(s-t)}ds-S(t)\right).$ This can be rewritten as a second-order ODE, i.e., $\ddot{S}-(r^{*}+\xi-r^{S'})\dot{S}-r^{*}(\xi-r^{S'}+\theta r^{S}/p)S=\left[r^{*}A+w\right]r^{*}\theta^{C}/p.$ The steady state is $S(\infty)=-(\theta^{C}/p)\left[r^{*}[A_{0}+V(0)]+w\right]/[\xi-r^{S'}+\theta^{C}r^{S}/p]\equiv\overline{S}.$ Restricting the solution to the stable manifold and provided that A_0 is negative enough, we get the winding down of structures:

$$S(t)=\overline{S}\left(1-e^{-\omega t}\right)+S_{0}e^{-\omega t},\quad \overline{S}\equiv\frac{-\theta^{C}\left[r^{*}[A_{0}+V(0)]+w(\overline{p})\right]}{\overline{p}[\xi-r^{S'}(\overline{p})]+\theta^{C}r^{S}(\overline{p})}>0,$$
$$\omega\equiv 0.5\sqrt{(r^{*}+\xi-r^{S'})^{2}+4(\xi-r^{S'}+\theta^{C}r^{S}/\overline{p})}-0.5(r^{*}+\xi-r^{S'})>0,$$

with $Y(\overline{p},S)=w(\overline{p})L+r^{S}(\overline{p})S$ and $r^{S'}<0.$ Substituting this equation into the present value budget constraint, we get $e(\overline{p})C=r^{*}[A_{0}+V(0)]+w+r^{*}r^{S}\int_{0}^{\infty}\left[\overline{S}\left(1-e^{-\omega t}\right)+S_{0}e^{-\omega t}\right]e^{-r^{*}t}dt,$ which can be solved to give $e(\overline{p})C=r^{*}[A_{0}+V(0)]+w+r^{S}\overline{S}+r^{*}r^{S}(S_{0}-\overline{S})/(r^{*}+\omega).$ Using the definition of $\overline{S}$, we obtain the effect of the windfall on real consumption is:

$$\frac{e(\overline{p})dC}{d[r^{*}V(0)]}=1-\frac{\theta^{C}r^{S}}{\overline{p}(\xi-r^{S'})+\theta^{C}r^{S}}\frac{\omega}{r^{*}+\omega}\leq 1.$$

The definition of $\overline{S}$ indicates that a windfall curbs the long run stock of structures, but less strongly if the price of structures is high and its expected life is short (i.e., if $\overline{p}$ and ξ are high); more strongly if the share of non-tradables in the consumption basket (θ^C) is high. If no non-tradables are consumed ($\theta^C = 0$), there is zero impact of the windfall on structures. The speed of winding down home-grown capital (ω) is high if the consumption share of non-tradables (θ^C) is high. The sustained increase in consumption resulting from the windfall is less than the annuity value of the windfall; more so if the consumption share of non-tradables is high. This is achieved in the short run by borrowing and in the long run by curbing structures.

5. Genuine savings and need for a parking fund (section 3)

Since the price of non-tradables also is the asset price of structures, initial assets $A_0^F+V(0)+p(0)S_0$, jump up on impact due to the direct effect of the windfall and the indirect effect of the upward revaluation of structures. Genuine savings for this economy is defined as the change in net non-human wealth of the nation and is given by $\dot{W}=\dot{A}+\dot{p}S+p\dot{S}=r^{*}W+w-C,$ where $W\equiv A+pS$ defines total non-human wealth of the nation. The constant marginal value of wealth upon news of the windfall is given by:

$$\lambda = \left(\frac{r^* \int_0^\infty e(p(t))^{1-\sigma} e^{-r^* t} dt}{r^* \left[A_0 + p(0) S_0 + V(0) \right] + w} \right)^{1/\sigma}.$$

If $\sigma = 1$, intertemporal substitution and income effects cancel out so that the marginal value of wealth equals the inverse of interest income on total non-human and human wealth of the country. In that case, genuine saving is zero, $\dot{W} = 0$. Total wealth jumps up on impact and stays at this higher level and the same is true for consumer spending. Because sovereign assets held abroad decline over time in regime (a), the value of structures, $p\,S$, rises over time as total wealth is constant if $\sigma = 1$. Build-up of domestic structures must thus be completely offset by a corresponding contraction of assets held abroad.

Genuine saving may not be zero if $\sigma \neq 1$. To see this, note that $\dot{W} = r^* W + w - \lambda^{-\sigma} e(p)^{1-\sigma}$ cannot be zero if p varies with time. Consider first regime (b) of Proposition 2 with tradables intensive in structures so p does not adjust. We then have that genuine saving is zero for all values of σ. Total wealth jumps up on impact by the present value of the windfall and stays at this level forever thereafter. So the gradual reduction in structures is associated with a gradual buildup of foreign assets. Consider now regime (a) of proposition 2 where the non-traded sector is intensive in structures and p falls with time. To gain understanding of the dynamic wealth effects, we linearize and solve the model to get:

$$p(t)^{\theta^C(1-\sigma)} = p^{*\theta^C(1-\sigma)} + \left[p(0)^{\theta^C(1-\sigma)} - p^{*\theta^C(1-\sigma)} \right] \exp(-\omega t),$$

where $\omega > 0$ is the absolute value of the eigenvalue with negative real part. We then get:

$$\lambda \cong \left(\frac{r^* p(0)^{\theta^C(1-\sigma)} + \omega p^{*\theta^C(1-\sigma)}}{r^* + \omega} \frac{1}{r^* \left[A_0^F + V(0) + p(0) S_0 \right] + w} \right)^{1/\sigma} = \lambda(p(0), n), \quad \lambda_p, \lambda_n < 0,$$

The saddlepoint system gives $p(0) = \pi(\lambda), \pi_\lambda < 0$. We thus have $\lambda = \lambda(\pi(\lambda), n) = \lambda(n)$, $\lambda' = \lambda_n / (1 - \lambda_p \pi_\lambda) < 0$ provided that $\lambda_p \pi_\lambda < 1$. Substituting the above expression for λ into the asset dynamics, we get the following evolution of total assets:

$$\dot{W} = r^* W + w - \left[r^* W(0) + w \right] \left(\frac{(r^* + \omega) p^{\theta^C(1-\sigma)}}{r^* p(0)^{\theta^C(1-\sigma)} + \omega p^{*\theta^C(1-\sigma)}} \right).$$

For genuine saving and the evolution of sovereign assets, it is important to note that the term in the big round brackets equals 1 and thus $\dot{W} = 0$ if $\sigma = 1$ as shown above. However, as $p(0) > p^*$, this term is on impact bigger (less) than one if σ is less (greater) than 1. Hence, initially, we have negative, zero, or positive genuine saving if σ is less than 1, equal to 1, or greater than 1. Hence, the contractions in net foreign assets dominate (fall short of) the increases in the value of structures if $\sigma < 1$ (> 1). If it is easy to substitute future for present consumption, $\sigma > 1$, total wealth increases over time, $\dot{a} > 0$. If $\sigma < 1$, total wealth decreases, $\dot{W} < 0$.

6. Specific factors

With specific factors, $Y_{KK} < 0$ and thus $\Delta p = (-Y_{KK} / Y_{pK})\Delta K$ from (5). We also have from (2′) and (3) that $e(p)\Delta C = r^* V(0),$ so that (7) still holds. Totally differentiating (3) and using these two results, we obtain the changes in the price of non-tradables and the capital stock:

$$\Delta p = \frac{\theta^C}{\varepsilon^D + \varepsilon^S - \dfrac{pY_{pK}^2}{Y_p Y_{KK}}} \frac{r^* V(0)}{Y_p} > 0 \quad \text{and} \quad \Delta K = \frac{Y_{pK}}{-Y_{KK}} \frac{\theta^C}{\varepsilon^D + \varepsilon^S - \dfrac{pY_{pK}^2}{Y_p Y_{KK}}} \frac{r^* V(0)}{Y_p},$$

where $\varepsilon^D \equiv -pe_{pp} / e_p > 0$ and $\varepsilon^S \equiv pY_{pp} / Y_p > 0$ are the elasticities of demand for and supply of non-tradables with respect to the price of non-tradables. If $Y_{KK} = 0,$ these expressions collapse to $\Delta p = 0$ and $p\Delta K = \theta^C r^* V(0) / Y_{pK}$, thus confirming (8) in Proposition 1.

Example: Let $X^N = F^\alpha (L - L^T)^{1-\alpha}$ and $X^T = K^\alpha (L^T)^{1-\alpha}$, where F is the fixed factor. Wage equalization across sectors implies $p(1-\alpha)[F / (L - L^T)]^\alpha = (1-\alpha)(K / L^T)^\alpha = w,$ so $L^T = L\left(\dfrac{K}{K + p^{1/\alpha}F}\right)$ and $L^N = L\left(\dfrac{p^{1/\alpha}F}{K + p^{1/\alpha}F}\right)$. Setting L = 1, we have the GNP function $Y(p,K,F) = \left(K + p^{1/\alpha}F\right)^\alpha$. We thus get $Y_p = F\left(p^{-1/\alpha}K + F\right)^{\alpha-1}, Y_{pK} = -(1-\alpha)Fp^{-1/\alpha}\left(p^{-1/\alpha}K + F\right)^{\alpha-2}$ and $Y_{KK} = -\alpha(1-\alpha)\left(K + p^{1/\alpha}F\right)^{\alpha-2}$. The change in the price of non-tradables is thus $\Delta p = \dfrac{\theta^C}{\varepsilon^D + \varepsilon^S + \left(\dfrac{1-\alpha}{\alpha}\right)\left(\dfrac{F}{p^{-1/\alpha}K + F}\right)} \dfrac{r^* V(0)}{Y_p} > 0$ and the change in capital is $\Delta K = \dfrac{Y_{pK}}{-Y_{KK}} \Delta p < 0.$ Capital has to contract as tradables are capital intensive. The increase in the price of non-tradables is smaller if the fixed factor used in production of non-tradables is larger.

Introducing a specific fixed into the model of section 3 if the non-traded sector is sufficiently structures intensive, $Y_{pS} > \delta$, alters panel (a) of Figure 1 as the $\dot{p} = 0$ locus now slopes upwards and the saddle path slopes downwards. Following a windfall, there is cut in the social value of wealth λ which pushes out the $\dot{S} = 0$ locus. We thus establish that the real exchange rate undershoots, as in part (a) of Proposition 2 and the price of non-tradables overshoots.

If the traded sector is structures intensive, $Y_{pS} < 0$, panel (b) of Figure 1 changes as the $\dot{p} = 0$ locus and the saddle path now slope downwards. In contrast to part (b) of Proposition 2, we see that the price of non-tradables undershoots: it jumps up on impact and then continues to rise to its new higher long run value. As a result, it is easy to establish that real consumption no longer adjusts instantaneously but overshoots its new long run value.

7. Derivation of (23) and (24)

We analyse the system:

$$\begin{bmatrix} \dot{K}^N \\ \dot{p} \end{bmatrix} = \begin{bmatrix} a & b \\ 0 & d \end{bmatrix} \begin{bmatrix} K^N - \left(K_0^N + \Delta K^N\right) \\ p - \overline{p} \end{bmatrix}.$$

Routine calculation (which may be easily checked by differentiation and substitution) indicates that the solution for an unanticipated windfall occurring at time zero equals

$K^N(t) = K_0^N + \Delta K^N\left(1 - e^{-\xi t}\right)$ and $p(t) = \overline{p} + \left(\dfrac{a-d}{b}\right)\Delta K^N e^{-\xi t}$. With fixed coefficients in the production of capital goods $p = \left(1 - \tilde{\beta}\right) + \tilde{\beta}\, p$. Linearizing gives $a \equiv Y_{pK^N} / \tilde{\beta} - \delta^N > 0$, $b \equiv S_p / \tilde{\beta} > 0$ and $d \equiv (r^* + \delta) - Y_{pK^N} / \tilde{\beta} < 0$, where $S(p,K) = K^N r_p\left(p, \overline{w}\right) - e_p(p)\left[e(p)\lambda\right]^{-\sigma}$ defines the excess of non-tradable production over consumption of non-tradables. Since the determinant of the Jacobian matrix of this system, *ad*, is negative, the system displays saddle point dynamics. The speed of adjustment ξ is given by the modulus of the eigenvalue of the Jacobian matrix with negative real part, that is using *a*+*d*=*r**: $\xi = -\frac{1}{2}r^* + \frac{1}{2}\sqrt{r^{*2} - 4ad} = -\frac{1}{2}r^* + \frac{1}{2}\sqrt{r^{*2} + 4\left[\left(Y_{pK^N} / \tilde{\beta}\right) - \delta^N - r^*\right]\left[\left(Y_{pK^N} / \tilde{\beta}\right) - \delta^N\right]} =$ $\left(Y_{pK^N} / \tilde{\beta}\right) - (\delta^N + r^*) > 0$. We already know that $\Delta K^N = \dfrac{e_p(\overline{p})\Delta C}{Y_{pK^N} - \delta^N \tilde{\beta}}$, so that

$p(0) = \overline{p} + \left(\dfrac{2Y_{pK^N} - \tilde{\beta}(2\delta^N + \rho)}{Y_{pK^N} - \delta^N \tilde{\beta}}\right)\dfrac{e_p(\overline{p})\Delta C}{Z_p}$. Hence, $\dfrac{\partial p(0)}{\partial \tilde{\beta}} = -\left(\dfrac{\rho Y_{pK^N}}{(Y_{pK^N} - \delta^N \tilde{\beta})^2}\right)\dfrac{e_p(\overline{p})\Delta C}{Z_p}$ is negative for a positive value of ΔC.