Dutch Disease and Carbon Pricing in Resource-Rich Economies

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Abstract

A large literature has argued that foreign exchange windfalls associated with natural resource wealth extraction can decrease economic growth by shifting resources away from sectors that induce endogenous productivity growth. Recent work has studied this "Dutch disease" phenomenon from a normative perspective by exploring the optimal intertemporal allocation of foreign exchange windfalls. This paper seeks to add to this literature in two ways. First, I add an explicit fossil fuel extraction sector to a benchmark Dutch disease model of a small open economy with traded and non-traded goods sectors. I use this framework to characterize policies and specifically fossil fuel tax sequences that can *decentralize* the optimal resource allocation. Second, I add a climate change externality to the model. I then characterize optimal fossil fuel tax schedules that can address both Dutch disease and climate change. The central qualitative finding is that policies designed to address climate change can aid in mitigating Dutch disease, and vice versa: both sources of inefficiency can be addressed through appropriate sequences of fossil fuel taxes in energy-rich economies.

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1 Introduction

It is well-known that resource-rich economies must manage their natural endowments with great care in order to avoid the economic pitfalls that excessive extraction and consumption out of this wealth may bring. One of these pitfalls is *Dutch disease*: the phenomenon that natural resource sales (1) lead to an appreciation of the real exchange rate, which (2) leads to a contraction in the traded sector (e.g., manufacturing), which, in turn, (3) may decrease economic growth rates by inhibiting learning-by-doing in the traded sector (e.g., Corden and Neary, 1982; Sachs and Bruno, 1982, etc.). Alternatively, some authors have also suggested windfall wealth absorption constraints in the non-traded sector as a mechanism for Dutch disease (e.g., van der Ploeg and Venables, 2013). While a large literature has studied Dutch disease (see recent reviews by van der Ploeg (2011) and Frankel (2010)), these studies commonly model resource wealth as an exogenous foreign exchange gift, and abstract from optimal extraction. An important exception, Matsen and Torvik (2005) solve for the optimal allocation of a foreign exchange gift through lump-sum transfers across generations, but do not focus on policies that can decentralize this optimal allocation.

This paper revisits the question of optimal resource management in the presence of Dutch disease, and formally integrates these considerations with another element of increasingly widespread policy interest: climate change. Specifically, this paper seeks to add to the Dutch disease literature in two ways. First, by integrating an explicit oil extraction sector into the standard Dutch disease model of a small resource-rich economy with a traded and non-traded goods (building closely on Matsen and Torvik, 2005). I use this setup to characterize policies that can decentralize the optimal resource extraction paths, and show that this can be done through a sequence of oil taxes. Second, I extend the model to incorporate an intertemporal climate change externality due to cumulative oil consumption (building on Hassler and Krusell, 2012, who focus on resource extraction and climate change but not Dutch disease). I then use this setup to characterize petroleum tax sequences that can decentralize the optimal allocation in addressing *both* Dutch disease and the climate externality. The central qualitative result is that policies designed to address climate change can aid in mitigating Dutch disease, and vice versa: both sources of inefficiency can be addressed through appropriate sequences of fossil fuel taxes in energy-rich economies.

The policy relevance of this finding can be motivated by three key observations. First, a growing number of energy-rich economies have expressed an interest or begun experimenting with carbon pricing policies (which include and/or imply fossil fuel taxation). For example, Kazakhstan was the first Asian country to implement a pilot carbon trading scheme. Further examples of countries with a publicly stated interest or actual policies in place include Iran, Brazil, Mexico, Sweden, and Norway, inter alia. Second, Hassler and Krusell (2012) find that, in some cases, carbon pricing in oil producing countries may be the *only* way to slow climate change. That is, climate policy in energy-consuming economies may be ineffective, thus giving the presence of such policies in energy-rich countries critical importance in addressing global climate change. Third, as several resource-rich economies struggle significantly due to the fall of oil prices in late 2014, the importance of economic diversification and effective policies to manage resource wealth is once again a salient public policy question. While this paper focuses on a very simple setting and abstracts from many important issues that have been studied in the Dutch disease and broader resource curse literatures (e.g., uncertainty, sovereign wealth funds, political economy considerations, etc.), the central focus is once again on complementarities between climate and Dutch disease management.

The rest of the paper is structured as follows. Section 1.1 sets up the key features of the model and highlights the standard Dutch disease mechanism, closely following Matsen and Torvik (2005). Section 1.2 sets up the planner's problem and derives the conditions governing the optimal allocation. Section 1.3 considers the decentralized economy and derives an implicit expression for the optimal fossil fuel tax sequence to address Dutch disease and implement the optimal allocation. Section 2 extends the model to consider a climate change externality, and derives an implicit expression for the optimal tax sequence to address *both* climate change and Dutch disease. [*Work in progress: Section 3 will present a quantitative illustration, solving for* *optimal fossil fuel tax sequences numerically to highlight how consideration of Dutch disease alters standard optimal carbon tax prescriptions.] Section 4 concludes.*

2 Model

2.1 General Setup

Consider a small, energy-rich, open economy with three production sectors: oil E_t, other traded goods T_t, and non-traded goods N_t. A key departure from standard Dutch disease frameworks such as Matsen and Torvik (2005, "MT") is that the resource sector is modeled explicitly. The country is endowed with stock R_0 of oil, which can be costlessly extracted, thus yielding the flow resource constraint:

$$E_t \leq R_t - R_{t+1} \tag{1}$$

In MT, the planner receives a foreign exchange gift and decides how to allocate it across generations. In the current setting, perfectly competitive firms are assumed to operate in the oil extraction sector. The government must thus first solve for the optimal allocation - including of oil revenues - over time, and then find a policy sequence that can decentralize this allocation.

One of the key assumptions of the model is that there is learning-by-doing (LBD) from work in the traded sector.[1] Following MT and hence Sachs and Warner (1995), I assume that LBD benefits all sectors, yielding balanced growth. Letting η_t denote the share of labor employed in the traded sector, productivity A_t evolves according to:

$$\frac{A_{t+1} - A_t}{A_t} = \alpha \eta_t \tag{2}$$

[1] See Torvik (2001) for an analysis of Dutch disease when both sectors can contribute to productivity growth.

where $\alpha \geqslant 0$ indicates the degree of LBD, as in MT. Labor is inelastically supplied and the aggregate labor supply is normalized to one: $L_t = L_t^T + L_t^N = 1$. In line with much of the literature on resource extraction in small open economies, I assume that the energy-rich country does not consume oil itself but only exports it.[2] Consequently, output in each sector evolves according to:

$$\begin{aligned} Y_t^T &= A_t \eta_t \\ Y_t^N &= A_t(1-\eta_t) \end{aligned}$$

Letting p_t^N denote the relative price of the non-traded good in terms of the traded good (with the price of the traded good normalized to one), total produced output Y_t is given by:

$$Y_t \equiv Y_t^T + p_t^N Y_t^N$$

In much of the Dutch disease literature, including MT, resource wealth is represented by a foreign exchange gift which governments receive in the first period. MT study how the planner should allocate this gift over time in the form of lump-sum transfers to households. Here, I focus on explicitly modeling oil extraction instead. Letting p_{Et}^* denote the world price of oil in period t - which the country takes as given - national disposable income Ω_t at each point in time t is given by:

$$\Omega_t = Y_t + p_{Et}^* E_t$$

Before proceeding to the planner's problem and the main part of the paper, I briefly review the intuition for Dutch disease as illustrated by MT. First, in line with MT, I model household preferences as Cobb-Douglas over the traded and non-traded goods with $\gamma \in (0,1)$ denoting the share of income devoted to traded goods. Consequently, and as demonstrated formally

2 This assumption is made, e.g., by, Hassler and Krusell (2012), Daubanes and Grimaud (2010), etc. In contrast, Beverelli, Dell'Erba, and Rocha (2011) study specifically how domestic resource usage in the resource-exporting economy affects the standard Dutch disease mechanism.

below, the solution to the problem of the representative consumer in the resource-rich economy at time t thus satisfies:

$$c_t^N = (1-\gamma)\frac{\Omega_t}{p_t^N} \tag{3}$$

In words, this expression indicates that households spend fraction $(1-\gamma)$ of disposable income on the non-tradable good. On the supply side, since the non-traded good can only be obtained through domestic production, its resource constraint is given by:

$$c_t^N = Y_t^N = A_t(1-\eta_t) \tag{4}$$

Equating demand (3) and supply (4) for the non-traded good thus determines the equilibrium fraction of workers employed in the traded sector:

$$\eta_t = 1-(1-\gamma)\frac{\Omega_t}{A_t p_t^N} = 1-(1-\gamma)\frac{(Y_t + p_{Et}^* E_t)}{A_t p_t^N} \tag{5}$$

Equation (5) shows what MT refer to as the "static" Dutch disease effect: employment in the traded sector (η_t) is decreasing in resource wealth generated in period t. Intuitively, this is because increased resource wealth increases domestic demand for both traded and non-traded goods. While traded goods can be imported to meet this increase in demand, the non-traded good must be produced at home, requiring increased labor supply and thus decreasing employment in the traded sector. At this stage, the novelty in (5) relative to MT is limited to illustrating the roles of oil prices and oil production: an increase in global oil prices or an increase in domestic production both serve to increase domestic wealth in period t, and hence the Dutch disease effect. As in MT, the setup with equal productivities and constant returns to scale in production of the non-energy traded good and the non-traded good implies a relative price $p_t^N = 1$, and that $Y_t = A_t$. Consequently, (5) becomes:

$$\eta_t = \gamma - (1-\gamma)\frac{p_{Et}^* E_t}{A_t} \tag{6}$$

The dynamic implication of (6) can be seen by substituting it into the law of motion or productivity (2), yielding:

$$A_{t+1} = (1 + \alpha\gamma)A_t - (1 - \gamma)\alpha p^*_{Et} E_t \tag{7}$$

Equation (7) showcases the classic Dutch disease effect: An increase in time t oil revenues ($p^*_{Et} E_t$) decreases future productivity A_{t+1} by increasing demand for and thus employment in non-tradable goods. Consequently, the resource-rich country misses out on LBD in other traded goods production sectors, such as manufacturing.

2.2 The Planner's Problem

The social planner's problem is to maximize the discounted lifetime utility of the representative household,

$$\max \sum_{t=0}^{\infty} \beta^t \left[\gamma \log c_t^T + (1 - \gamma) \log c_t^N\right]$$

subject to the following constraints, with Lagrange multipliers indicated in square brackets:

1. Consumption of the non-traded good c_t^N cannot exceed production of the non-traded good $[\lambda_{nt}]$:

$$c_t^N \leq A_t(1 - \eta_t)$$

2. Consumption of the traded good c_t^T cannot exceed domestic production and imports from revenues of oil production $[\lambda_{Tt}]$:

$$c_t^T \leq p^*_{Et} E_t + A_t \eta_t$$

3. Oil extraction must obey the resource constraint (1) $[\mu_t]$.

4. Productivity A_{t+1} evolves according to LBD and the equilibrium allocation of labor across sectors (7) $[\lambda_{At}]$.

Setting up the planner's problem subject to these constraints, taking the first order conditions, and rearranging them appropriately yields the following conditions for the optimal allocation. First, as expected, consumption across sectors is allocated based on the relative preference intensity for traded and non-traded goods:

$$\frac{\gamma}{(1-\gamma)} = \frac{c_t^T}{c_t^N} \tag{8}$$

Second, the domestic shadow value of oil in the ground (in utils per unit of oil) grows based on the pure rate of social time preference:

$$\frac{\mu_{t+1}}{\mu_t} = \frac{1}{\beta} \tag{9}$$

Third, and most importantly, the social marginal benefit (SMB) of oil extraction is given by the following condition:

$$\underbrace{\frac{\mu_t}{\lambda_{Tt}}}_{\substack{\text{SMB of oil in} \\ \text{units of tradeable good}}} = \underbrace{p_{Et}^*}_{\substack{\text{Marginal value of oil exports} \\ \text{in units of tradeable good}}} - \underbrace{\frac{\lambda_{At}}{\lambda_{Tt}}(1-\gamma)\alpha p_{Et}^*}_{\substack{\text{Marginal productivity cost of Dutch} \\ \text{disease (in units of tradeable good)}}} \tag{10}$$

In words, expression (10) says that the social marginal benefit of oil extraction equals the value of the tradable goods that can be purchased from export revenues, minus the "Dutch disease" negative productivity effect due to the exchange rate appreciation and corresponding sectoral re-allocation of labor away from the traded sector that occurs in response to the increased oil revenues. Combining equations (9) and (10), reveals a Hotelling-type condition for the optimal evolution of the returns to extracting oil over time:

$$\frac{p^*_{Et+1}}{p^*_{Et}} \frac{[\lambda_{T_{t+1}} - \lambda_{At+1}(1-\gamma)\alpha]}{[\lambda_{T_t} - \lambda_{At}(1-\gamma)\alpha]} = \frac{1}{\beta} \tag{11}$$

One of the central arguments of this paper is that a decreasing sequence of ad-valorem oil (or carbon) taxes can implement the optimal allocation as defined by (11), as discussed in further detail below. A final optimality condition for the economy is an Euler equation for productivity investments:

$$\lambda_{At} = \beta\left[\lambda_{Tt+1} + \lambda_{At+1}(1+\alpha\gamma)\right] \tag{12}$$

Intuitively, equation (12) indicates that the marginal cost of making investments in productivity today should equal the discounted marginal benefit of increased productivity in the next period. The latter consists of both the relaxation of the tradable good resource constraint λ_{Tt+1} and the increased future productivity due to persistence in A_t.

2.3 Decentralized Economy

Households: I assume an infinitely-lived, representative household with Cobb-Douglas preferences over consumption of traded and non-traded goods. The household's problem is to maximize his present discounted lifetime utility subject to the following flow budget constraint:[3]

$$c^T_t + p^N_t c^N_t \leq L^T_t w^T_t + L^N_t w^N_t + \pi_t + G_t$$

where L^i_t and w^i_t denote labor supplied and wages earned in sector i at time t, π_t denotes profits from the energy production sector, and G_t denotes net transfers from the government. Letting q_t denote the price of consumption of the traded good in period t (expressed in period

[3] Note that, following much of the literature, I abstract from private savings as well as from public investment of oil resources in international assets. In reality, resource-rich countries face several options on how to use their windfall incomes, including domestic and foreign investments (see, e.g., discussion by Collier, van der Ploeg, Spence, and Venables, 2010).

0 units), and noting as above that $p_t^N = 1$ due to equal productivities, the consumer's problem subject to the present-value version of the budget constraint is thus:

$$\max \sum_{t=0}^{\infty} \beta^t \left[\gamma \log c_t^T + (1-\gamma) \log c_t^N\right]$$
$$+\lambda \sum_{t=0}^{\infty} q_t \left[L_t^T w_t^T + L_t^N w_t^N + \pi_t + G_t - c_t^T - c_t^N\right]$$

The household's first order conditions for consumption are given by:

$$\begin{aligned}
[c_t^T] &: \quad \gamma \frac{1}{c_t^T} = \lambda q_t \\
[c_t^N] &: \quad (1-\gamma) \frac{1}{c_t^N} = \lambda q_t
\end{aligned}$$

There are two key implications. First, we see that the household's optimal allocation of income across consumption goods coincides with the planner's optimality condition (8):

$$\frac{\gamma}{(1-\gamma)} = \frac{c_t^T}{c_t^N}$$

The second is that the relative price of consumption over time evolves according to:

$$\frac{q_t}{q_{t+1}} = \frac{1}{\beta} \frac{c_{t+1}^T}{c_t^T} \tag{13}$$

Oil Producers: Oil production is assumed to be competitive, with a representative firm choosing its extraction schedule to maximize the present value of profits net of taxes τ_{Et}, taking the world price of oil as given and subject to the resource constraint:[4]

[4] Note that I do not explicitly model Hotelling profit taxes τ_{π_t} in the energy extraction sector as those are well-known to not affect extraction decisions (see, e.g., Dasgupta and Heal, 1979).

$$\max \sum_{t=0}^{\infty} q_t \{p^*_{Et}(1-\tau_{Et})E_t\}$$
$$+\sum_{t=0}^{\infty} q_t \widetilde{\mu}_t \left[R_t - E_t - R_{t+1}\right]$$

Taking and combining the oil sector's first order conditions with respect to extraction E_t and the leftover resource stock R_{t+1} yields the following intertemporal optimality condition:

$$\frac{p^*_{Et+1}}{p^*_{Et}} \frac{(1-\tau_{Et+1})}{(1-\tau_{Et})} = \frac{\widetilde{\mu_{t+1}}}{\widetilde{\mu}_t} = \frac{q_t}{q_{t+1}} \tag{14}$$

Proposition 1 *The optimal allocation of the small resource-rich economy's fossil fuel extraction over time can be implemented by a sequence of fossil fuel taxes satisfying the following condition (provided that all other prices and policies are set optimally):*

$$\frac{(1-\tau_{Et+1})}{(1-\tau_{Et})} = \frac{[1-\frac{\lambda_{At+1}}{\lambda_{Tt+1}}(1-\gamma)\alpha]}{[1-\frac{\lambda_{At}}{\lambda_{Tt}}(1-\gamma)\alpha]} \tag{15}$$

Proof: First, substituting the expression for the effective interest rate (or evolution of consumption prices over time) from the household problem (13) into (14) yields:

$$\frac{p^*_{Et+1}}{p^*_{Et}} \frac{(1-\tau_{Et+1})}{(1-\tau_{Et})} = \frac{1}{\beta} \frac{c^T_{t+1}}{c^T_t} \tag{16}$$

Next, based on the first order conditions of the social planner's problem with respect to c^T_t, we know that the growth rate in consumption of the tradable good equals the growth rate of the shadow value of the tradable good:

$$\frac{c^T_{t+1}}{c^T_t} = \frac{\lambda_{Tt}}{\lambda_{Tt+1}} \tag{17}$$

Finally, substituting (17) into (16), comparing this condition with the socially optimal Hotelling-type equation (11), and rearranging terms yields the desired result. $\square$.

Intuitively, this result simply states that the optimal allocation of a country's fossil energy extraction wealth over time can be decentralized by appropriately structured ad-valorem taxes on fossil fuels. The general idea that export taxes can be used to mitigate Dutch disease is also discussed by Bresser-Pereira (2012).

3 Climate Change and Carbon Pricing

So far, the discussion has focused on ad-valorem taxes of oil. Since oil is the only energy source considered in the model, any ad-valorem oil tax can be expressed as equivalent carbon tax by measuring oil E_t in units of carbon-equivalent.[5] This section extends the basic setup and focuses the discussion on carbon taxation by formally integrating climate change damages into the model. In particular, let S_0 denote the initial stock of carbon in the atmosphere. Carbon emissions from our resource-rich economy E_t combine with rest-of-the-world emissions E_t^{ROW} to add to the carbon stock according to some weakly increasing function:

$$S_t = F_t(S_0, E_0 + E_0^{ROW}, E_1 + E_1^{ROW}, ..., E_t + E_t^{ROW}) \tag{18}$$

The impacts of increased atmospheric carbon concentrations S_t are most commonly modeled as an equivalent loss to productivity (e.g., Nordhaus, 2008, 2010; Golosov, Hassler, Krusell, and Tsyvinski, 2014, etc.), though some studies express impacts as pure utility losses (e.g., Acemoglu, Aghion, Bursztyn, and Hemous, 2012) or as mixture of market and non-market impacts (e.g., MERGE, Manne and Richels, 2005; PAGE2002, Hope, 2006; Tol, 1995). Barrage (2014) separates the sectoral-regional climate change impacts underlying the seminal DICE model calibration (Nordhaus and Boyer, 2000) and argues that the majority of global impacts affect production possibilities. However, in a multi-regional model with trade, potentially heterogeneous productivity impacts of climate change raise both interesting but

[5] Further note that using oil implies burning the carbon content and thus causing emissions, implying that oil extraction E_t measured in tons of carbon-equivalent can also be considered as emissions.

complex issues with regards to potential trade impacts (for a detailed discussion of heterogeneity and climate impacts see, e.g., Krusell and Smith, 2014). As the simplest benchmark, I thus first model climate change as affecting utility directly and separably (as it would, e.g., due to impacts on biodiversity existence value losses, non-productivity or work-related health impacts, etc.), with new representative household utility:

$$U_0 = \sum_{t=0}^{\infty} \beta^t \left[\gamma \log c_t^T + (1-\gamma) \log c_t^N + v(S_t) \right] \tag{19}$$

where $v'(S_t) < 0$ and $v''(S_t) > 0$. It should be noted that, while $v(S_t)$ denotes the domestic disutility due to climate change in our resource-rich economy, there are also damages in the rest of the world. Denote these damages (in units of the tradable good) as $D^{ROW}(S_t)$. There is some debate over whether official measures of the social cost of carbon used in a country's regulatory rulemakings (see Interagency Working Group, 2010) should include international or only domestic damages. For example, Nordhaus (2010) estimates the Nash equilibrium carbon price for the United States in 2015 to be only \$4.28 (\$/mtC in \$2005), compared to an optimal global carbon price of approximately \$40 per ton. One of the central implications of the findings in this section is that consideration of Dutch disease can serve as mechanism to increase nationally optimal carbon prices above strictly domestic environmental damages in resource-rich economies.

The revised (selfish) social planner's problem maximizes (19) subject to the same constraints as in the previous section alongside (18) as additional constraint $[\lambda_{St}]$, taking rest-of-the-world emissions as given. In contrast, an altruistic social planner would further incorporate $D^{ROW}(S_t)$ into the objective function. The resulting revised optimality condition indicating the social marginal benefit of domestic oil extraction is given by:

$$\underbrace{\frac{\mu_t}{\lambda_{Tt}}}_{\substack{\text{SMB of oil in} \\ \text{units of } c_t^T}} = \underbrace{p_{Et}^*}_{\substack{\text{MV of oil exports} \\ \text{in units of } c_t^T}} - \underbrace{\frac{\lambda_{At}}{\lambda_{Tt}}(1-\gamma)\alpha p_{Et}^*}_{\substack{\text{Dutch disease} \\ \text{cost in units of } c_t^T}} - \underbrace{\sum_{j=0}^{\infty} \beta^j \frac{v'(S_{t+j})}{\lambda_{Tt}} \frac{\partial S_{t+j}}{\partial E_t}}_{\substack{\text{Present discounted value} \\ \text{of climate change damages}}} \tag{20}$$

Expression (20) illustrates that consideration of climate change and climate damages decreases the social marginal value of oil extraction (ceteris paribus). An altruistic planner would further subtract a welfare-weighted measure of the present discounted marginal damages in the rest of the world $D'^{ROW}(S_{t+j})$ from (20). Proceeding analogously to the previous section, it is straightforward to derive the following result:

Result The (nationally) optimal allocation in a setting with climate change and Dutch disease can be decentralized by a sequence of carbon taxes that satisfy:

$$\frac{(1-\tau_{Et+1})}{(1-\tau_{Et})} = \frac{\left[1 - \frac{\lambda_{At}}{\lambda_{Tt+1}}(1-\gamma)\alpha - \left(\sum_{j=1}^{\infty} \beta^j \frac{v'(S_{t+j})}{\lambda_{Tt+1}} \frac{\partial S_{t+j}}{\partial E_{t+1}}\right) \frac{1}{p_{Et+1}^*}\right]}{\left[1 - \frac{\lambda_{At}}{\lambda_{Tt}}(1-\gamma)\alpha - \left(\sum_{j=0}^{\infty} \beta^j \frac{v'(S_{t+j})}{\lambda_{Tt}} \frac{\partial S_{t+j}}{\partial E_t}\right) \frac{1}{p_{Et}^*}\right]} \tag{21}$$

Intuitively, the optimal tax sequence thus subtracts the present discounted value of the social cost of carbon emissions from each period's oil price. The key point is thus that consideration of climate change and Dutch disease go hand in hand: both sources of inefficiency require fossil energy tax sequences to slow extraction compared to the laissez-faire allocation.

4 Quantitative Analysis

[To be completed]

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