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Dutch Disease Dynamics Reconsidered*

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Abstract

In this paper we develop the first model to incorporate the dynamic productivity consequences of both the spending effect and the resource movement effect of oil abundance. We show that doing so dramatically alters the conclusions drawn from earlier models of learning by doing (LBD) and the Dutch disease. In particular, the resource movement effect suggests that the growth effects of natural resources are likely to be positive, turning previous growth results in the literature relying on the spending effect on their head. We motivate the relevance of our approach by the example of a major oil producer, Norway, where it seems clear that the predictions based on existing theory do not apply. Although the effects of an increase in the price of oil may resemble results found in the earlier Dutch disease literature, the effects of increased oil activity do not. Therefore, models that only focus on windfall gains due to increased spending potential from higher oil prices, would conclude - incorrectly based on our analysis - that the resource sector cannot be an engine of growth.

JEL-codes: C32, E32, F41, Q33

Keywords: Dutch disease, resource movements, learning by doing, oil prices, time-varying VAR model

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1 Introduction

The North American shale revolution has turned the United States in the space of only a few years into a net exporter of oil and gas. Technological developments in drilling and fracking since the turn of this century have unlocked the huge reserves that lie trapped in shale rock. This has had major implications for the economic development of the US. However, contrary to predictions based on the influential theory of Dutch Disease, there has been no crowding out of the manufacturing sector so far. Instead, the oil boom seems to have benefited local industries in the US., see e.g. Allcott and Keniston (2018) for some recent empirical evidence. Norway, where the oil sector has been a main engine of growth for a few decades, has experienced something similar, see e.g. Bjørnland and Thorsrud (2016), while in countries such as Angola and Venezuela on the other hand, decades of oil abundance has led to lower productivity and income levels, see e.g. Mehlum et al. (2006).

One of the most influential explanations of the Dutch disease is that of the Learning By Doing (LBD) models of van Wijnbergen (1984), Krugman (1987) and Sachs and Warner (1995). According to these approaches, a country that discovers oil is essentially in receipt of a foreign exchange gift. The gift increases income, and with traded and non-traded goods both being normal goods, the increase in demand pushes workers out of the traded sector and into the non-traded sector; the increased demand for traded goods can be satisfied by using the foreign exchange gift; while the increased demand for non-traded goods can only be satisfied by getting a larger share of the labour force to produce non-traded goods. This structural transformation of the economy, however, means that labour is transferred from strong to weak LBD sectors. Economic growth is pushed down.

While these theoretical approaches can explain the negative economic developments observed in countries such as Angola and Venezuela, they fail to describe what is going on in oil producing countries such as Norway. This can be illustrated by comparing the economic development of Norway with that of its neighbour Sweden. When Norway in 1969 discovered oil in the North Sea, its GDP per capita was 65 percent that of Sweden. By 2014, GDP per capita was almost 150 percent of Sweden's. Most observers would agree that although Norway initially had very limited knowledge of offshore drilling and petroleum technology, the experience it has gained as an oil producer for more than 40 years is one of the main reasons for Norway's favourable economic development. For example, Norway has today a highly skilled and productive petroleum related service and supply industry, and the knowledge created by this industry is one of the main contributors to the high levels of income enjoyed in Norway, again see Bjørnland and Thorsrud (2016) for some empirical evidence.

However, it has not always been this way. In the early years, foreign companies dominated exploration and were responsible for developing the country's first oil and gas fields. Yet gradually, and as a result of a deliberate policy requiring national participation, the country gained experience and was able to adapt its traditional engineering skills from shipbuilding to the development of oil exploration and drilling technologies able to

(a) Employment **(b)** Productivity

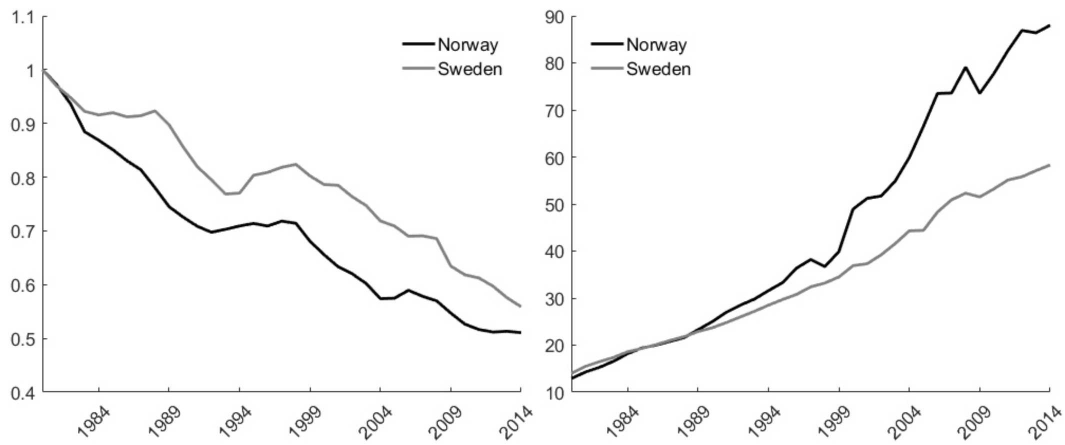

Figure 1. Stylized facts. Figure 1a shows the employment share in traded sectors, normalized to 1 in 1980. Figure 1b reports the productivity level in the overall economy. Source: Statistics Norway, Statistics Sweden and authors own calculations.

withstand conditions at sea and on land in Norway.[1] These experiences and advances in technology have extended the extractable amount of oil and gas in Norway's petroleum reserves, transforming Norwegians from passive recipients of windfall gains into exporters of technical knowledge on a global scale. In fact, the stock of knowledge built up by the oil industry during these years has, we would contend, been of significant benefit to many other industries.

Why did the theories of LBD and the Dutch Disease run ashore? We suggest in this paper, that they did so because they exclusively incorporated the productivity dynamics of the spending effect, but failed to take into account the productivity dynamics of the resource movement effect. Indeed, already the influential contributions of Corden and Neary (1982) and Corden (1984) had as a main emphasis that becoming an oil producer would affect the general equilibrium of a nation's economy through the spending effect - oil means more income and thus higher demand - and through the resource movement effect - factors of production need to be transferred to the oil sector. When these models were applied to dynamic settings by incorporating knowledge creation, however, the new models developed incorporated the spending effect, but not the resource movement effect. This holds true not only for the models of van Wijnbergen (1984), Krugman (1987) and Sachs and Warner (1995), but also later models of LBD and the Dutch Disease such as those by Gylfason et al. (1999), Torvik (2001) and Matsen and Torvik (2005). In fact, to the best of our knowledge, no single model in the literature appears to incorporate productivity dynamics of the resource movement effect.[2]

That incorporating both could be crucial can again be illustrated by comparing the

[1] Rough weather conditions in the North Sea, stringent regulations, as well as demanding operators are among the factors that have contributed to the development of Norway's technologically world-leading petroleum service and supply industry.

[2] Also important theoretical contributions before the introduction of LBD into the Dutch disease models, i.e., Bruno and Sachs (1982a,b), abstract from the resource movement effect.

economic trajectories of Sweden and Norway. As seen from panel (a) in Figure 1, the share of employment in the traded sector has fallen considerably faster in Norway than it has in Sweden. This is fully consistent with the theories of van Wijnbergen (1984), Krugman (1987) and Sachs and Warner (1995). Panel (b), however, shows that despite this decline, productivity growth has been considerably higher in Norway relative to Sweden. This is not consistent with those theories, but suggests instead that there may have been an important change *within* the traded sector: while the share of employment in traditional industry has decreased, more of the traded sector employment operates in oil related activities, and less in the traditional activities. While this change has been across industries, more importantly, it has occurred within industries. Shipyards workers who used to be welders, are today experienced in complex deep sea technology. Such a development becomes disguised in models that abstract from the resource movement effect.

To study this development we need to understand the role of oil related industry as an engine for growth, which, requires in turn the approaches of van Wijnbergen (1984), Krugman (1987), Sachs and Warner (1995), Gylfason et al. (1999), Torvik (2001) and Matsen and Torvik (2005) to include a resource movement effect. To take an example, textile manufacturing used to be an important industry in Norway; it is less so today, because the oil service industry has taken its place. While one might certainly believe that the textile industry has stronger knowledge creation than non-traded sectors, it would be difficult to argue that experience in textile production has stronger productivity effects than experience in deep sea technology. An approach that focuses solely on the productivity dynamics of the spending effect, while ignoring the productivity dynamics of the resource movement effect, is likely to focus on the least important productivity dynamics, while overlooking the most important ones.

In this paper we extend the literature by developing a dynamic three sector model that incorporates the productivity dynamics from the spending as well as the resource movement effect. We show that this dramatically alters the conclusions from earlier models of LBD and the Dutch disease. In particular, the resource movement effect implies that the growth effects of natural resources are likely to be positive, reversing previous growth results in the literature relying solely on the spending effect. To capture the different effects, we specify a model that allows for different structural shocks to oil prices and to oil activity. In the earlier theoretical literature, the effects following these two disturbances were assumed to be the same, and most empirical analyses of the empirical relevance of the Dutch disease hypothesis in resource rich economies therefore concentrated on the oil price, see e.g. Charnavoki and Dolado (2014) for an application to Canada. However, we show theoretically that an increase in oil income can have a very different effect on the economy if it comes either via increased oil prices, on the one hand, or via from increased production or productivity in the resource sector, on the other.

To investigate empirically the potential productivity spillovers and the dynamic adjustment after oil market shocks, we estimate a time varying Vector Autoregressive (VAR) model for a major oil producer (Norway) to recover structural disturbances, and use local linear projections to trace out the productivity responses across a broad set of sectors. We focus on Norway; a small open country, but with large share of oil in the economy. In the VAR model we include three variables; global activity, real oil prices and oil activity, with associated structural shocks, global activity shocks, oil price shocks and a resource boom, all motivated by the theoretical model presented here and findings in the recent oil-macro literature. Important to our set-up is the separation of a windfall gain due to resource movement and spending effects. This allows the domestic economy to respond differently to a windfall gain due to increased activity in the petroleum sector (i.e., the discovery of new productive fields or increased extraction rates) and a windfall gain due to higher oil prices. Global activity is included in the VAR model, mainly to control for international business cycle conditions that can affect both the oil price and the petroleum sector. This allows us in turn to identify two oil market shocks: a global activity shock and an oil price shock, both of which increase the real price of oil, though with potentially very different macroeconomic implications for the other industries in the resource rich economy. Finally, the VAR is specified with time varying parameters to allow for changes (over time) in the productivity dynamics due to learning, while also controlling for changes in the volatility of the shocks.

Although the empirical strategy is simple, our results are striking. A resource boom that increases productivity (value added per worker) in the oil and gas service industries, increases productivity significantly in nearly all industries, including manufacturing. Hence, value added per worker increases with the oil boom, as predicted by the theory model in a setting of learning by doing in the oil service industries, and spills over to the other industries. In contrast, we find no such productivity spillovers following an oil price shock. Hence, models that focus on windfall gains due to an increase in spending potential resulting from higher oil prices, would likely conclude (incorrectly) that the resource sector cannot be an engine of growth.

In addition to the literature on LBD and Dutch Disease, our paper is related to four other strands of the literature. First, we relate to several recent papers using cross-sectional data that document strong positive spillovers to the rest of the economy following oil discoveries, in particular the recent fracking boom in North America, see e.g. Weber (2012), Allcott and Keniston (2018), Beine et al. (2015), Feyrer et al. (2017) and Gilje et al. (2016). Despite different methods, areas of study and time frames, the results presented in these recent empirical papers stand in contrast to the predictions of the dominating theoretical models of van Wijnbergen (1984), Krugman (1987) and Sachs and Warner (1995), but are fully consistent with the theoretical predictions of our model.

Second, our paper relates to the literature of van der Ploeg and Venables (2011, 2013) who study optimal spending of resource income in developing countries. In these papers the economy (or a sector within the economy) is constrained by capital, such that to extract a more favourable effect from the spending of oil income, the economy, or a sector of it, will first have to expand. Although ours is a very different model, where productivity dynamics are endogenous, a common feature of our approach and these papers is that the effects of oil activity are conditional on the initial sectoral structure of the economy.

Third, by focusing on the challenges experienced by highly volatile resource prices, our paper relates to contributions by van der Ploeg and Poelhekke (2009), Leong and Mohaddes (2011) and Robinson et al. (2017) that point to different channels by which resource price volatility could hurt an oil producing economy. None of these approaches incorporate productivity dynamics from the resource movement effect; i.e., the main mechanisms in our model, nor to they analyse the dynamic effects of oil and gas booms on oil related industries.

Fourth, our paper contributes to the literature on the resource curse. A well established result in this literature, see e.g. Mehlum et al. (2006) and Boschini et al. (2007), is that resource abundance increases aggregate income when institutions are strong, but decreases aggregate income when institutions are weak. Although we do not model institutional differences between countries per se, our model clarifies a possible mechanism for this finding that has not previously been pointed out. When institutions are weak, oil abundance will most likely not result in the development of a domestic oil service industry. In such countries, therefore, the spending effect of resource abundance may be the dominant. In countries with strong institutions, on the other hand, a domestic oil service industry is more likely to develop. In these countries, the resource movement effect therefore comes into play. Since the latter effect, in our model, is more likely to increase income than the former effect, this is one possible explanation of the diverging effects of resource abundance between countries with weak and with strong institutions. So while oil activity may contribute to growth in e.g. Norway or in the US, it may be less likely to do so in e.g. Venezuela or in Angola. In these countries, as well in other countries with weak institutions, the oil services are typically imported from abroad.

The rest of the paper is organized as follows. In Section 2 we set up a three sector model incorporating the need of the oil sector for domestic resources in order to extract oil. We allow for endogenous productivity growth in all three sectors: the non-traded sector; the traded sector; and the oil service sector. In Section 3 we discuss the static effects in the model. Section 4 looks at the dynamic equilibrium and steady state growth, while Section 5 analyses the dynamics of an increased oil price and of increased oil activity. In Section 6 we present the empirical application and results. Section 7 concludes.

2 The Model

In this section, we develop a model of an oil economy which, in addition to oil extraction, includes production of oil services as necessary inputs to the extraction oil, production of non-traded goods, and production of traditional traded goods. We let each good be produced in a separate sector. This sector structure is assumed for notational purposes only and is without loss of generality insofar as nothing prevents goods grouped in different sectorsfromo being produced by the same firm. The main novelty of the model is to extend the earlier literature on learning by doing and the Dutch disease by incorporating the resource movement effect, endogenous productivity dynamics in the production of all goods, as well as the possibility of learning spillovers.

2.1 Technology and Preferences

We thus consider an economy consisting of three sectors, and we denote the oil service sector by S, the non-traded sector by N, and the traded sector by T. The size of the labour force is normalized to unity, and at each point in time t employment in the oil service sector is denoted l_t, employment in the non-traded sector n_t, and, given full employment, employment in the traded sector by $1 - l_t - n_t$. We denote the output of sector i at time t by X_{it}, and the productivity of sector i at time t by H_{it}, $i \in \{S, N, T\}$.

The oil industry depends on the services of the oil service sector, and at each point in time the labour used in the oil service sector increases in the quantity of oil extracted, and (given the quantity extracted) decreases in the productivity level of the sector. Denoting the oil extraction measured in traded sector productivity units at time t by R_t, implying that $H_{Tt}R_t$ is the oil extraction measured in traded sector goods units, employment in the oil service sector is given by

$$l_t = \frac{\alpha}{H_{St}} H_{Tt} R_t, \tag{1}$$

with $\alpha \geq 0$, and where $\frac{\alpha}{H_{St}}$ is the labour requirement for each unit of oil extraction. A higher productivity level in the oil service sector implies a lower labour requirement. The higher $\alpha$is, the stronger the resource movement effect of oil activity. The standard two-sector model with a traded and non-traded sector, that assumes away the resource movement effect, arises as the special case of the model where $\alpha = 0$.

Production in the non-traded sector is given by

$$X_{Nt} = H_{Nt} f(n_t), \quad f'(n_t) > 0, \quad f''(n_t) < 0, \tag{2}$$

and production in the traded sector by

$$X_{Tt} = H_{Tt} g(1 - n_t - l_t), \quad g'(1 - n_t - l_t) > 0, \quad g''(1 - n_t - l_t) < 0. \tag{3}$$

We allow for learning by doing in all sectors, as well as learning spillovers between them. Denoting $\dot{H}_{St}$ as the derivative of H_{St} with respect to time, and so on, the productivity dynamics are governed by the following thee differential equations:

$$\frac{\dot{H}_{St}}{H_{St}} = ql_t + \delta_N u n_t + \delta_T v(1 - n_t - l_t), \tag{4}$$

$$\frac{\dot{H}_{Nt}}{H_{Nt}} = u n_t + \delta_S q l_t + \delta_T v(1 - n_t - l_t), \tag{5}$$

$$\frac{\dot{H}_{Tt}}{H_{Tt}} = v(1 - n_t - l_t) + \delta_S q l_t + \delta_N u n_t. \tag{6}$$

In these equations the three first terms on the right hand side; ql_t, un_t, and $v(1-n_t-l_t)$, represent the direct learning by doing effects in the oil service sector, the non-traded sector, and the traded sector, respectively. We assume that q, u, $v \geq 0$, ruling out the possibility of negative learning by doing. The remaining terms on the right hand sides of these three equations represent learning spillovers, where $\delta_S q l_t$, $\delta_N u n_t$, and $\delta_T v(1-n_t-l_t)$

are the learning spillovers from the oil service sector, the non-traded sector, and the traded sector, respectively. We assume that $0 \leq \delta_i \leq 1$, $i \in \{S, N, T\}$, where the first inequality rules out the possibility of negative learning spillovers, and the second inequality rules of the possibility of indirect learning effects dominating direct learning effects.

The earlier models of learning by doing and the Dutch disease arise as special cases of these more general learning mechanisms; all the previous models assume that $\alpha = 0$, and in addition van Wijnbergen (1984) and Krugman (1987) assume that $q = u = \delta_S = \delta_N = \delta_T = 0$, Sachs and Warner (1995) and Matsen and Torvik (2005) that $q = u = \delta_S = \delta_N = 0$ and $\delta_T = 1$, and Torvik (2001) that $q = \delta_S = 0$. Thus, the earlier literature on learning by doing and the Dutch disease has focused exclusively on different productivity dynamics arising from the spending effect. We extend the literatureby incorporating the resource movement effect.

Consumers allocate their spending between the consumption of non-traded goods C_{Nt} and consumption of traded goods C_{Tt} according to a CES utility function. Each consumer is too small to take into account how her consumption demand affects the productivity growth of the aggregate economy. We normalize the number of consumers to one, and the per period utility function U_t of this consumer is given by

$$U_t = \frac{\sigma}{\sigma - 1} C_{Nt}^{\frac{\sigma-1}{\sigma}} + \frac{\sigma}{\sigma - 1} C_{Tt}^{\frac{\sigma-1}{\sigma}}, \quad \sigma > 0,$$

where σ is the (constant) elasticity of substitution.

At time t, the total value of production in the economy is given by the sum of income from the production of non-traded and traded goods, plus the total income from oil extraction. The total income Y_t of the economy measured in traded sector goods units at time t is given by

$$Y_t = P_t X_{Nt} + X_{Tt} + Q_t H_{Tt} R_t, \tag{7}$$

where P_t is the real exchange rate, i.e. the price of non-traded goods relative to traded goods, and Q_t is the world market real oil price, i.e. the price of oil relative to traded goods. In (7) we have incorporated that the income from the oil service sector plus the remaining net income from oil extraction, equals gross income $Q_t H_{Tt} R_t$ in oil extraction.

The real exchange rate is endogenous, while the real oil price is taken as exogenous by our small open economy, as both the oil price and the price of traded goods are assumed to be given at the world market. Since there are no (net) financial nor real assets, income must equal consumption at each point in time, and the demand for non-traded goods is, consequently, given by

$$C_{Nt} = \frac{Y_t}{P_t + P_t^{\sigma}}. \tag{8}$$

3 Static Equilibrium

In this section we solve the model, determine the static equilibrium, and investigate the effects of an increase in the oil price Q_t and an increase in the oil activity level, R_t. This will clarify the connections to, and the differences from, the existing literature. An oil price shock, as we have modelled it, isolates the spending effect of oil income.[3] An oil activity shock, on the other hand, also introduces the resource movement effect of oil income in the static model.

At each point in time t, the levels of productivity in the three sectors are determined by history, and a static equilibrium is defined as a set of relative prices and factor allocations that satisfy the following constraints: the supply of non-traded goods equals the demand of non-traded goods; the supply of labour equals the demand for labour (which has already been incorporated since labour in the traded sector is given by $1 - n_t - l_t$ which ensures full employment); consumers maximize utility and producers maximize profits given the factor prices and prices of final goods.

Starting with the constraint that demand must equal supply of non-traded goods $X_{Nt} = C_{Nt}$, we insert from (2) on the left hand side, and on the right hand side first from (8), then from (7) and finally from (3), (2) and (1) to yield

$$H_{Nt} f(n_t) = \frac{P_t H_{Nt} f(n_t) + H_{Tt} g\left(1 - n_t - \frac{\alpha}{H_{St}} H_{Tt} R_t\right) + Q_t H_{Tt} R_t}{P_t + P_t^\sigma}.$$

Defining the relative productivities

$$\lambda_t \equiv \frac{H_{Tt}}{H_{Nt}},$$

and

$$\gamma_t \equiv \frac{H_{Tt}}{H_{St}},$$

the non-traded market balance equation may be rewritten as a function of relative (and not absolute) productivities[4]:

$$P_t = \left(\frac{g\left(1 - n_t - \alpha \gamma_t R_t\right) + Q_t R_t}{f(n_t)}\right)^{\frac{1}{\sigma}} \lambda_t^{\frac{1}{\sigma}}. \tag{9}$$

Since the relative productivities are predetermined, this equation is one equation in the two endogenous variables P_t and n_t, depicted as the downward sloping solid curve denoted NN in Figure 2a.

To see the underlying intuition, start out with supply equal to demand in the non-traded sector. From such an equilibrium, assume that employment in the non-traded sector increases. For equilibrium to be reestablished at this new labour allocation, a real exchange rate depreciation (lower P_t) must take place, since higher demand is required to bring the market back to balance at the new and higher supply. The real depreciation achieves this by shifting demand towards non-traded goods.

[3]The property that an oil price shock has no resource movement effect holds in our static model, since in the static model an increased oil price (for a given level of activity in the oil sector) only affects income, not employment in the oil service sector. As we discuss below when we study transitional dynamics, however, there is an endogenous dynamic resource movement effect from an oil price shock.

[4]Also, note for later reference that with these definitions, it follows that the productivity in the oil service sector relative to the non-traded sector is given by $\frac{H_{St}}{H_{Nt}} = \frac{\lambda_t}{\gamma_t}$.

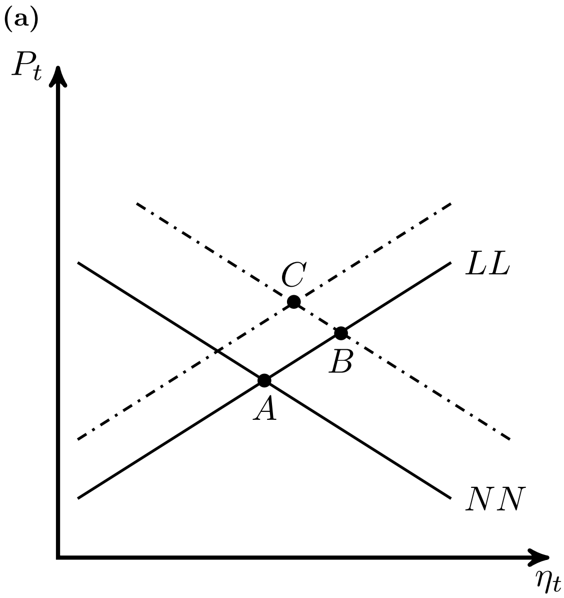

Figure 2. Static Equilibrium. Figure 2a shows the effect of: Increased oil price (A to B), increased oil activity (A to C), and higher productivity in traded versus non-traded production (A to C). Figure 2b shows the effect of higher productivity in traded versus oil service production (A to B).

A static equilibrium also requires firms to maximize profits and the labor market to be in equilibrium. This implies that the value of the marginal productivity of labor must be equal (to the wage) in traded and non-traded production:

$$P_t H_{Nt} f'(n_t) = H_{Tt} g'\left(1 - n_t - \alpha\gamma_t R_t\right).$$

This condition can be rewritten as

$$P_t = \frac{g'\left(1 - n_t - \alpha\gamma_t R_t\right)}{f'(n_t)}\lambda_t. \tag{10}$$

At each point in time, the labour market equilibrium (10) can be represented by a positive relationship between the real exchange rate P_t and the employment share in the non-traded sector n_t, as depicted by the solid curve LL in Figure 2a. To see the intuition for this, start out in labour market equilibrium, and then allow the real exchange rate P_t to appreciate. At the new real exchange rate production in the non-traded sector has become more profitable relative to production in the traded sector. To again equalize the values of the marginal productivities at full employment, employment in the non-traded sector has to increase and employment in the traded sector decrease. This decreases the marginal productivity of labour in the non-traded sector, and increases the marginal productivity in the traded sector, again equalizing the values of the marginal productivities of labour at the new real exchange rate.

The initial unique static equilibrium is represented by the intersection of the two solid curves at point A in Figure 2a.[5]

[5]Note that the same static equilibrium applies with an infinite number of possible distributions of income,

3.1 Static Dutch Disease - Increased Oil Price

We now investigate the response of the static equilibrium to an increased the oil price. What is often referred to as Dutch disease is shown in Figure 2a, as the movement from the initial equilibrium A to the new static equilibrium B. As seen from (9) and (10), Q_t affects the NN curve, but not the LL curve. A higher oil price increases income, pushing demand for non-traded goods up, and thus for any given labour allocation, the price of non-traded goods has to be higher to ensure market balance. The upward shift in the NN curve to the dotted curve in Figure 2a produces the two common symptoms associated with the Dutch disease: higher employment in the non-traded sector and a real exchange rate appreciation.

3.2 Static Dutch Disease - Increased Oil Activity

Consider now the effect of increased oil activity R_t, due, for instance, to new discoveries of oil, or new technological opportunities making new forms of extraction possible (such as deep sea drilling in the North Sea, the shale revolution in the US, or improvements enabling not only vertical drilling but horizontal too). Throughout we consider the natural case where these possibilities are profitable, i.e. that the oil price is sufficiently high that $Q_t - g'\alpha\gamma_t > 0$. If this were not the case, the oil is of so little value that the income lost because alternative production decreases is higher than the income gained by extracting the oil. In such a case, income is higher by not using the new opportunities, and thus the static equilibrium is not affected. The only interesting case to study is therefore that in which the new oil activity is actually profitable.

Consider first the NN curve. When oil extraction R_t increases, again the demand for non-traded goods increases, and again this spending effect of oil income shifts the NN curve up, as in Figure 2a.[6] The size of the vertical shift in the NN curve is found from (9), and given by

$$\frac{1}{\sigma}\frac{(1-g'\alpha\gamma_t)}{f(n_t)}\left(\frac{g\,(1-n_t-\alpha\gamma_t R_t)+Q_t R_t}{f(n_t)}\right)^{\frac{1}{\sigma}-1}\lambda_t^{\frac{1}{\sigma}}=\frac{1}{\sigma}\frac{(1-g'\alpha\gamma_t)}{g+Q_t R_t}P_t>0.$$

Turning next to the LL curve, a higher R_t also shifts this curve up; higher oil activity

profits and wages between oil extraction income and the oil service sector. The only relevant variable for the mechanisms we are studying is the total income from the oil service industry plus the remaining income from oil extraction (after they have purchased their inputs from the oil service industry). Thus, without any loss of generality, we do not need to specify the interactions between the oil service industry and oil extraction. One possibility, among many, is that there is full mobility of labour into and out of the oil service sector, implying that the wage in this sector equals the wage in the other sectors. The price of the output from the oil service sector then determines how much profit will remain in the sector (possibly zero), and how much income will remain from oil extraction after purchasing servces from the oil service industry. In any case, the sum of income from the oil service sector and oil extraction measured in traded goods units is given by $Q_t H_{Tt} R_t$.

[6] In Figure 2a, for simplicity, we have drawn the same size of the shift in the NN curve as when we studied a higher oil price above, although ,in general, the size of the shifts differ.

requires more labour in the oil service sector. For a given employment share in the non-traded sector n_t, the real exchange rate (and the wage level) must increase, making production in the traded sector less profitable, and thereby enabling increased labour use in the oil service sector. The shift to the dotted LL curve in Figure 2a represents the resource movement effect of higher oil activity. The size of the vertical shift in the LL curve is found from (10), and given by

$$\frac{-\alpha\gamma_t g''}{f'(n_t)}\lambda_t = \frac{-\alpha\gamma_t g''}{g'}P_t > 0.$$

The total effect is a new static equilibrium at point C in Figure 2a. The spending effect and the resource movement effect both contribute to a real exchange rate appreciation. As a consequence, employment in the traded sector must unambiguously fall, again both as a result of the spending effect and the resource movement effect. Employment in the oil service sector increases, and employment in the non-traded sector increases if the spending effect dominates, but decreases if the resource movement effect dominates. Which of these effects dominates is determined by the size of the vertical shift in the NN and LL curves. If the former is the largest, then the spending effect dominates and employment in the non-traded sector increases. As can be seen from the expression, the spending effect dominates when (and only when)

$$\sigma < \frac{1 - g'\alpha\gamma_t}{-\alpha\gamma_t g''}\frac{g'}{g + Q_t R_t}$$

Thus, the spending effect will always dominate provided the elasticity of substitution σ and/or the labour requirement in the oil service sector α is sufficiently small, while the resource movement effect will always dominate if the opposite is the case.

To summarize the effects in the static model, a higher oil price means higher employment in the non-traded sector, lower employment in the traded sector, and a real exchange rate appreciation. Higher oil activity also means lower employment in the traded sector and a real exchange rate appreciation. Employment in the oil service sector increases, while the effect on employment in the non-traded sector is ambiguous.

3.3 Effects of Relative Productivity

Before turning to the dynamics of the model, we need to find out how the static equilibrium responds to changes in relative productivities. Consider first the case of a higher λ_t, i.e. higher productivity in the traded relative to the non-traded sector. As seen from (9) the vertical shift in NN is given by

$$\frac{1}{\sigma}\left(\frac{g\left(1 - n_t - \alpha\gamma_t R_t\right) + Q_t R_t}{f(n_t)}\right)^{\frac{1}{\sigma}} \lambda_t^{\frac{1}{\sigma}-1} = \frac{P_t}{\sigma\lambda_t} > 0,$$

while from (10) the vertical shift in LL is given by

$$\frac{g'\left(1 - n_t - \alpha\gamma_t R_t\right)}{f'(n_t)} = \frac{P_t}{\lambda_t} > 0.$$

Thus, the shifts depicted in Figure 2a can also represent this case. As seen, higher productivity in the traded versus the non-traded sector appreciates the real exchange rate (the Balassa-Samuelson effect) and, when the elasticity of substitution falls short of unity, increases employment in the non-traded sector while decreasing it the in the traded sector. When the elasticity of substitution exceeds unity, this shift decreases employment in the non-traded sector while it increases employment in the traded sector.

Consider next the case of a higher γ_t, i.e. higher productivity in the traded sector relative to the oil service sector. As seen from (9) the vertical shift in NN, depicted by the dotted curve in Figure 2b, is given by

$$\frac{1}{\sigma}\left(\frac{-g'\alpha R_t}{f(n_t)}\right)\left(\frac{g\left(1-n_t-\alpha\gamma_t R_t\right)+Q_t R_t}{f(n_t)}\right)^{\frac{1}{\sigma}-1}\lambda_t^{\frac{1}{\sigma}}=\frac{1}{\sigma}\frac{(-g'\alpha R_t)}{g+Q_t R_t}P_t<0,$$

while from (10) the vertical shift in LL, again depicted by the dotted curve in Figure 2b, is given by

$$\frac{-\alpha R_t g''}{f'(n_t)}\lambda_t=\frac{-\alpha R_t g''}{g'}P_t>0.$$

The intuition underlying the downward shift in the NN curve is that a higher γ_t (for a given λ_t) means that the oil service industry has become less productive relative to the rest of the economy, increasing the amount of labour needed in this sector, and thus reducing production in the rest of the economy as less labour is available. In turn, this implies decreased income, a drop in demand, and lower relative prices of non-traded goods. The intuition for the upward shift in the LL curve is that when the oil service industry needs more labour relative to the other sectors, then the increased demand for labour pushes wages up, and therefore, for a given employment share in the non-traded sector, the price P_t must increase.

As seen by comparing the initial point A to the new point B in Figure 2b, the result of a higher γ_t is a lower employment share in the non-traded sector, while the effect on the real exchange rate is uncertain, reflecting opposite forces derived from the market balance for non-traded goods and from the equilibrium condition for the labour market.

We can summarize the employment response in the static model by

$$\begin{aligned} n_t &= n(Q_t, R_t, \lambda_t, \gamma_t),\ \text{with} \\ \frac{dn}{dQ_t} &> 0,\ \frac{dn}{dR_t}>0 \text{ iff } \sigma<\frac{1-g'\alpha\gamma_t}{-\alpha\gamma_t g''}\frac{g'}{g+Q_t R_t},\ \frac{dn}{d\lambda_t}>0 \text{ iff } \sigma<1,\ \frac{dn}{d\gamma_t}<0. \end{aligned} \tag{11}$$

4 Dynamic Equilibrium

Having examined the static version of the model, we now study the dynamic properties of the model. We start with five differential equations and discuss how the model can be solved analytically, before exploring the stability properties of the dynamic system. We thereafter discuss the steady state of the model.

By inserting for the employment response in the static model, the dynamic model can be represented by five differential equations:

$$\frac{\dot{\lambda}_t}{\lambda_t} = \frac{\dot{H}_{Tt}}{H_{Tt}} - \frac{\dot{H}_{Nt}}{H_{Nt}}, \tag{12}$$

$$\frac{\dot{\gamma}_t}{\gamma_t} = \frac{\dot{H}_{Tt}}{H_{Tt}} - \frac{\dot{H}_{St}}{H_{St}}, \tag{13}$$

$$\frac{\dot{H}_{St}}{H_{St}} = q\alpha\gamma_t R_t + u\delta_N n(Q_t, R_t, \lambda_t, \gamma_t) + v\delta_T(1 - n(Q_t, R_t, \lambda_t, \gamma_t) - \alpha\gamma_t R_t), \tag{14}$$

$$\frac{\dot{H}_{Nt}}{H_{Nt}} = un(Q_t, R_t, \lambda_t, \gamma_t) + q\delta_S\alpha\gamma_t R_t + v\delta_T(1 - n(Q_t, R_t, \lambda_t, \gamma_t) - \alpha\gamma_t R_t), \tag{15}$$

$$\frac{\dot{H}_{Tt}}{H_{Tt}} = v(1 - n(Q_t, R_t, \lambda_t, \gamma_t) - \alpha\gamma_t R_t) + q\delta_S\alpha\gamma_t R_t + u\delta_N n(Q_t, R_t, \lambda_t, \gamma_t), \tag{16}$$

Although we have five differential equations, we will see that it is entirely possible to investigate the dynamics analytically without resorting to simulations. To study the dynamic equilibrium, as well as the transitional dynamics, we first reduce the dimensions of this system by studying the dynamics of relative productivities. After finding the steady state, as well as the transitional dynamics of these relative productivities, we can then, as we will see, back out the remaining dynamics for absolute productivity and income growth.

Inserting (14), (15) and (16) in (12) and (13) the differential equations for relative productivities read

$$\frac{\dot{\lambda}_t}{\lambda_t} = v\left(1 - \delta_T\right)\left(1 - n(Q_t, R_t, \lambda_t, \gamma_t) - \alpha\gamma_t R_t\right) - u\left(1 - \delta_N\right) n(Q_t, R_t, \lambda_t, \gamma_t), \tag{17}$$

and

$$\frac{\dot{\gamma}_t}{\gamma_t} = v\left(1 - \delta_T\right)\left(1 - n(Q_t, R_t, \lambda_t, \gamma_t) - \alpha\gamma_t R_t\right) - q\left(1 - \delta_S\right)\alpha\gamma_t R_t. \tag{18}$$

A steady state of this system is defined as a situation in which $\frac{\dot{\lambda}_t}{\lambda_t} = \frac{\dot{\gamma}_t}{\gamma_t} = 0$, and thus, by implication, that productivity growth is balanced between sectors.

To construct the phase diagram, we first need to discover how the growth rates of relative productivities respond to the levels of relative productivities. First, we find from (17) that

$$\frac{d\left(\frac{\dot{\lambda}_t}{\lambda_t}\right)}{d\lambda_t} = -\left(v\left(1 - \delta_T\right) + u\left(1 - \delta_N\right)\right)\frac{dn}{d\lambda_t}, \tag{19}$$

and that

$$\frac{d\left(\frac{\dot{\lambda}_t}{\lambda_t}\right)}{d\gamma_t} = -\left(v\left(1 - \delta_T\right) + u\left(1 - \delta_N\right)\right)\frac{dn}{d\gamma_t} - v\left(1 - \delta_T\right)\alpha R_t. \tag{20}$$

Next, we find from (18) that

$$\frac{d\left(\frac{\dot{\gamma}_t}{\gamma_t}\right)}{d\gamma_t} = -q\left(1 - \delta_S\right)\alpha R_t - v\left(1 - \delta_T\right)\alpha R_t - v\left(1 - \delta_T\right)\frac{dn}{d\gamma_t}, \tag{21}$$

and that

$$\frac{d\left(\frac{\dot{\gamma}_t}{\gamma_t}\right)}{d\lambda_t} = -v\left(1-\delta_T\right)\frac{dn}{d\lambda_t}. \tag{22}$$

The dynamic system is stable provided the trace and determinant conditions are both satisfied. The trace condition reads

$$\frac{d\left(\frac{\dot{\lambda}_t}{\lambda_t}\right)}{d\lambda_t} + \frac{d\left(\frac{\dot{\gamma}_t}{\gamma_t}\right)}{d\gamma_t} < 0,$$

which by inserting from (19) and (21) is equivalent to

$$-\left(v\left(1-\delta_T\right)+u\left(1-\delta_N\right)\right)\frac{dn}{d\lambda_t} - q\left(1-\delta_S\right)\alpha R_t - v\left(1-\delta_T\right)\alpha R_t - v\left(1-\delta_T\right)\frac{dn}{d\gamma_t} < 0.$$

The determinant condition reads

$$\frac{d\left(\frac{\dot{\lambda}_t}{\lambda_t}\right)}{d\lambda_t}\frac{d\left(\frac{\dot{\gamma}_t}{\gamma_t}\right)}{d\gamma_t} - \frac{d\left(\frac{\dot{\lambda}_t}{\lambda_t}\right)}{d\gamma_t}\frac{d\left(\frac{\dot{\gamma}_t}{\gamma_t}\right)}{d\lambda_t} > 0,$$

which, by inserting from (19) through (22), simplifies to

$$\frac{dn}{d\lambda_t}\left(\left(v\left(1-\delta_T\right)+u\left(1-\delta_N\right)\right)q\left(1-\delta_S\right)\alpha R_t + uv\left(1-\delta_N\right)\left(1-\delta_T\right)\alpha R_t\right) > 0.$$

Thus, for the determinant condition to be fulfilled, it is necessary *and* sufficient that $\sigma < 1$ (since $\frac{dn}{d\lambda_t} > 0$ iff $\sigma < 1$). In the continuation we thus assume that $\sigma < 1$. Given this, we note that the three first terms in the trace condition are all negative, and we assume that $\frac{d\left(\frac{\dot{\gamma}_t}{\gamma_t}\right)}{d\gamma_t} < 0$, which is a sufficient condition for the fourth term not to dominate the three negative terms. Given this, the trace condition is also satisfied, and the dynamic system given by (17) and (18) is stable.[7]

The phase diagram is shown in Figure 3. From (17) a curve between λ_t and γ_t, consistent with $\dot{\lambda}_t = 0$, follows. The slope of this curve is given by

$$\frac{d\lambda_t}{d\gamma_t}_{|\dot{\lambda}_t=0} = -\frac{\frac{d\left(\frac{\dot{\lambda}_t}{\lambda_t}\right)}{d\gamma_t}}{\frac{d\left(\frac{\dot{\lambda}_t}{\lambda_t}\right)}{d\lambda_t}} = -\frac{\frac{dn}{d\gamma_t} + \frac{v(1-\delta_T)\alpha R_t}{v(1-\delta_T)+u(1-\delta_N)}}{\frac{dn}{d\lambda_t}}. \tag{23}$$

Above the curve, it follows from (19) that λ_t is falling over time, while below the curve, λ_t increases over time. As depicted in Figure 3 the curve has a negative slope, which is

[7] If the system is not stable, we have a situation in which relative productivities approach zero or infinity. Such a case of unbalanced growth implies that, over time, the economy will asymptotically approach a situation where either no factors of production are in the non-traded sector, or no factors of production are in the traded sector. Although issues of such unbalanced long term growth are interesting per se, we do not pursue this topic further here, referring rather to the analyses of such unbalanced growth in e.g. Rauch (1997) or Torvik (2001). One should note, however, that although not discussed by Krugman (1987) himself, his model implies unbalanced productivity growth since he assumes exogenous productivity in the non-traded sector, while productivity growth in the traded sector is positive. An implication of his model is therefore, again without being discussed by Krugman himself, real exchange rate dynamics where the real exchange rate approaches infinity over time.

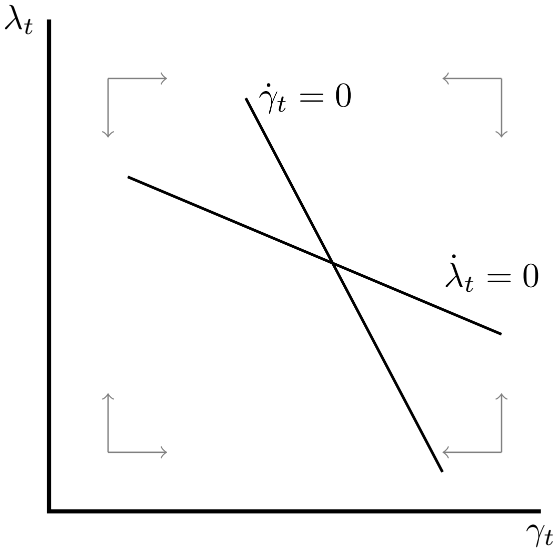

Figure 3. Phase diagram for relative productivities.

the case when $\frac{d\left(\frac{\dot{\lambda}_t}{\lambda_t}\right)}{d\gamma_t}$ from (20) is negative. We show the opposite possibility in Appendix A, and show that also when the curve has a positive slope essentially the same dynamics appear. The reason for this is that the other curve in the phase diagram, to which we now turn, always has a negative slope given our stability conditions.

A downward sloping curve between λ_t and γ_t consistent with $\dot{\gamma}_t = 0$ follows from (18). The slope of this curve is given by

$$\frac{d\lambda_t}{d\gamma_t}_{|\dot{\gamma}_t=0} = -\frac{\frac{d\left(\frac{\dot{\gamma}_t}{\gamma_t}\right)}{d\gamma_t}}{\frac{d\left(\frac{\dot{\gamma}_t}{\gamma_t}\right)}{d\lambda_t}} = -\frac{\frac{dn}{d\gamma_t} + \frac{q(1-\delta_S)\alpha R_t + v(1-\delta_T)\alpha R_t}{v(1-\delta_T)}}{\frac{dn}{d\lambda_t}} < \frac{d\lambda_t}{d\gamma_t}_{|\dot{\lambda}_t=0}, \tag{24}$$

where the latter inequality follows as the denominator of (23) and (24) is the same, while the numerator of (23) falls short of the numerator of (24). The latter follows as the condition for this is

$$q\left(1-\delta_S\right)\left(v\left(1-\delta_T\right)+u\left(1-\delta_N\right)\right)+uv\left(1-\delta_T\right)\left(1-\delta_N\right)>0,$$

which is always fulfilled. To the left of the curve it follows from $\frac{d\left(\frac{\dot{\gamma}_t}{\gamma_t}\right)}{d\gamma_t} < 0$ that γ_t is increasing over time, and to the right of the curve γ_t is falling over time.

The dynamic equilibrium is established at the intersection of the two curves in Figure 3. Here, both λ_t and γ_t are constant over time, and thus all sectoral productivities grow by the same (yet unknown) rate.

4.1 Steady State Growth

Consider now the case in which the economy has arrived at a steady state. Inserting $\dot{\lambda}_t = 0$ in (17), and solving for $\alpha\gamma_t R_t$ yields

$$\alpha\gamma_t R_t = 1 - n(Q_t, R_t, \lambda_t, \gamma_t) - \frac{u\left(1-\delta_N\right)n(Q_t, R_t, \lambda_t, \gamma_t)}{v\left(1-\delta_T\right)}. \tag{25}$$

Inserting $\dot{\gamma}_t = 0$ in (18), then substituting for $\alpha\gamma_t R_t$ from (25), and solving for $n(Q_t, R_t, \lambda_t, \gamma_t)$, provides the non-traded steady state employment share, which we denote by n^*, as

$$n^* = \frac{v(1-\delta_T)}{v(1-\delta_T) + u(1-\delta_N) + \frac{1}{q}\frac{v(1-\delta_T)u(1-\delta_N)}{(1-\delta_S)}}. \tag{26}$$

Note that the steady state employment share is constant, and, in particular that it is increasing in q, i.e. the stronger the learning by doing effect in the oil service sector. The intuition is that stronger learning in the oil service sector pushes productivity up, reducing the labour requirement in the sector. The increased productivity in the oil service sector thus allows for increased production and income in the rest of the economy. Some of this increased income potential is used to consume more non-traded goods. To bring forward these goods, employment in the non-traded sector increases.

We are now equipped to find steady state growth. First, note that in steady state the employment share is given by n^*, and that in (17) and (18) $\frac{\dot{\lambda}_t}{\lambda_t} = \frac{\dot{\gamma}_t}{\gamma_t} = 0$. Inserting this implies that the right hand side of (17) equals the right hand side of (18), which implies that in steady state

$$q\alpha\gamma_t R_t = \frac{u(1-\delta_N)\,n^*}{(1-\delta_S)}.$$

Inserting this in one of the equations (14), (15) or (16) provides the steady state growth rate of productivity, which we denote by g^*, as

$$g^* = n^*\left(\frac{u(1-\delta_N)}{(1-\delta_S)} + u\delta_N + v\delta_T\frac{u(1-\delta_N)}{v(1-\delta_T)}\right).$$

Note that, as labour allocations are constant in steady state, g^* is also the growth rate of income.

Since n^* is increasing in q, it follows that the steady state growth is increasing in the learning spillover from the oil service sector. Thus, the stronger the learning potential in the oil service sector, the more this sector serves as an engine of growth. It also follows, as n^* is independent of both Q_t and R_t, that the steady state growth rate is independent of resource abundance, whether it is measured by the price of the resource or the quantity of the resource.

Thus, any steady state effect of the oil price Q_t or the oil activity R_t must come via the level of income, not its growth rate.

5 Dynamic Dutch Disease

We now investigate the steady state effects of a higher oil price and of increased oil activity. In subsection 5.1 we first analyze how increased oil price affects steady state *relative* productivities, before turning to the more important question of how *absolute* productivities and income levels are affected. To trace out the latter, we must study the transitional dynamics from the old to the new steady state. In subsection 5.2 we undertake the same exercise for increased oil activity. As we will see, the steady state effects of a higher oil price differ considerably from the effects of increased oil activity, and, moreover, the effects of increased oil activity contrast with the results in the previous theories of learning by doing and the Dutch disease.

In a steady state with constant oil price and oil extraction we have from (18) and above that

$$\gamma^* R^* = \frac{u\,(1-\delta_N)\,n^*}{q\alpha\,(1-\delta_S)}. \tag{27}$$

Note in particular that this equation explicitly determines a *unique* value of $\gamma^* R^*$ that must hold in any steady state, irrespective of Q^*, R^*, and λ^*, since n^* is independent of all these three variables. (The same result can, of course, be established by using (17)).

Next, combining (9) and (10), and inserting the steady state labour share, we get

$$\left(\frac{g\,(1-n^*-\alpha\gamma^* R^*)+Q^* R^*}{f(n^*)}\right)^{\frac{1}{\sigma}} (\lambda^*)^{\frac{1}{\sigma}-1} = \frac{g'\,(1-n^*-\alpha\gamma^* R^*)}{f'(n^*)}.$$

Inserting from (27) for $\gamma^* R^*$ we find that

$$\left(\frac{g\left(1-n^*-\alpha\frac{u(1-\delta_N)n^*}{q\alpha(1-\delta_S)}\right)+Q^* R^*}{f(n^*)}\right)^{\frac{1}{\sigma}} (\lambda^*)^{\frac{1}{\sigma}-1} = \frac{g'\left(1-n^*-\alpha\frac{u(1-\delta_N)n^*}{q\alpha(1-\delta_S)}\right)}{f'(n^*)}. \tag{28}$$

Note in particular that this equation implicitly determines a steady-state value of λ^* that is *unique* given the value of $Q^* R^*$, i.e. λ^* can only change if there is a change in $Q^* R^*$; $\lambda^* = \lambda^*(Q^* R^*)$, with $\frac{d\lambda^*}{dQ^* R^*} < 0$ (where the latter can easily be verified as neither λ^* or $Q^* R^*$ appear on the right hand side of (28), while both λ^* and $Q^* R^*$ makes the left hand side of (28) higher).

With these preliminaries, we can now investigate the steady state effects of increased oil prices and thereafter, increased oil activity.

5.1 Increased Oil Price

When the oil price increases it follows from (27) that the steady state implication will be

$$\frac{d\gamma^*}{dQ^*} = 0,$$

while from (28) we find

$$\frac{\frac{d\lambda^*}{\lambda^*}}{dQ^*} = -\frac{R^*}{(1-\sigma)\,(g+Q^* R^*)} < 0.$$

Thus, in the new steady state, after a higher oil price, the relative productivity between the oil service sector and the traded sector is unchanged, while productivity in the traded sector (and by implication, the oil service sector) has fallen relative to productivity in the non-traded sector.

The dynamics of relative productivities are shown in Figure 4. The curves for $\dot{\lambda}_t = 0$ and $\dot{\gamma}_t = 0$ both shift down, and in such a way that the steady state level γ^* is unaffected

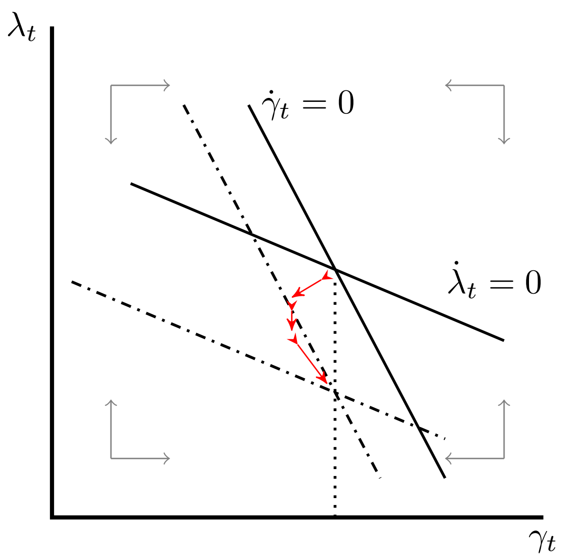

Figure 4. Phase diagram 2. Transitional dynamics and steady state effects of increased oil price.

as indicated by the dotted vertical curve. As can be seen, after the new and higher oil price the relative productivities λ_t and γ_t both fall over time. However, after this initial fall, at some point in time (when the new curve for $\dot{\gamma}_t = 0$ is crossed from above), γ_t starts to increase, bringing it back to its original value.

To see the intuition and the transitional dynamics, note that employment in the non-traded sector initially increases, while employment in the traded sector decreases. In consequence, productivity growth in the traded sector falls short of productivity growth in both the non-traded sector and oil service sector, since for the latter, *initial* employment is unchanged (and given by $\alpha\gamma_t R^*$). During the phase of transitional dynamics, however, employment in all three sectors changes. First, since traded sector productivity growth falls short of productivity growth in the non-traded sector, labour flows out of the non-traded sector and into the traded sector. Second, since traded sector productivity in the initial phases of the transition to the new steady state falls short of productivity growth in the oil service sector, labour also flows out of the oil service sector and into the traded sector. Over time, however, as labour in the traded sector increases relative to labour in the oil service industry, productivity growth in the latter exceeds productivity growth in the former. In the new steady state, the relative productivity between the traded sector and the oil service sector, and employment levels in all sectors, is back to initial levels.

1

5.1.1 Higher oil price and the level of productivity and income

Based on these dynamics, we can now discuss the impact on the absolute *level* of productivity, and, by extension, on aggregate income. To do so, note that during transition, employment in the non-traded sector must be above its steady state level, while employment in the oil service sector must be below its steady state level. To see this, note first that the latter follows since, during transition, $\gamma_t < \gamma^*$ and employment is given by $\alpha\gamma_t R^*$. But then it must be the case that employment in the non-traded sector is above its steady state level during transition. To prove this, suppose the opposite, such that at some point during transition we have $n_t < n^*$. Since, during transition, $\dot{\lambda}_t < 0$, it must be the case as derived from (17), that employment in the traded sector will also be below its steady state level. However, this is a contradiction: employment levels in all three sectors cannot all at any particular point in time below their steady state values. Thus, we have proved that during transition, $n_t > n^*$. Moreover, note also that at least in the initial phases of transition, we have that employment in the traded sector is below its steady state value. This follows since we already know that along transition, employment in the oil service sector is below its steady state level. Therefore, as long as $\dot{\gamma}_t < 0$, we have from (18) that employment in the traded sector must also be below its steady state level.

Consider first the case where indirect learning spillovers are negligible. Then, during transition, productivity growth in the non-traded sector is higher than in the steady state, while productivity growth in the oil service sector is lower than in the steady state. Thus, in such a case the new steady state productivity level in the non-traded sector is higher, while it is lower in the oil service industry. Moreover, productivity growth in the traded sector is also, at least initially, lower than in the steady state. Aggregate income may therefore, in the new steady state, perfectly well have decreased despite the higher oil price. This case resembles the classic Dutch disease in models incorporating the spending effect, but not the resource movement effect, such as van Wijnbergen (1984) and Krugman (1987). These models assume that there are only direct learning effects and that they are only relevant for the traded sector. Aggregate productivity is bound therefore to fall with higher oil prices.[8] In our model we have an additional effect pulling in the same direction, i.e., the dynamic resource movement effect, whereby productivity growth in the oil service sector is smaller during transition, thereby producing an additional force in the direction of a lower steady state productivity level.

Taking on board learning spillovers may strengthen this result for two reasons. First, as argued by Sachs and Warner (1995), if learning spillovers from the traded sector are strong, then lower productivity growth in the traded sector will spread over into lower productivity in the other sectors too. When this is the case, we get the Sachs and Warner (1995) result whereby productivity in both the traded and the non-traded sector decreases as oil income rises. Sachs and Warner get this as their unique result, since they assume there is only learning by doing in the traded sector, but a perfect spillover also to the non-traded sector.

Second, the present model clarifies a new mechanism that pulls in the same direction. When the learning spillovers from the oil service industry are strong, then, since the dynamic resource movement effect during transition pushes productivity growth in the oil service sector below its steady state level, the learning spillovers from this sector to the rest of the economy are also smaller.

[8] van Wijnbergen (1984) and Krugman (1987) no resource movement effect, and thus the traded sector employment is always lower with a higher oil price or higher oil activity. Therefore, since productivity growth only arises and benefits the traded sector (while productivity in the non-traded sector is exogenous), productivity growth and the aggregate productivity level are also lower.

To summarize, a rise in the oil price in the present model has an unclear effect on aggregate income. In isolation, the higher oil price in itself, as well as a higher level productivity in the non-traded sector relative to the traded sector, pulls in the direction of higher income with a higher oil price. However, the direct effects of weaker productivity growth in both the traded and the oil service sectors pull in the opposite direction, and the learning spillovers from these sectors become smaller as well. The stronger these effects, the more likely it is that aggregate income in a new steady state with a higher oil price will be lower.

Although we have clarified some new mechanisms compared to the previous literature on learning by doing and the Dutch disease, and in particular the dynamic resource movement effect, these results broadly resemble standard Dutch disease results: valuable natural resources may harm the economy. As we argued in the introduction, however, held against the experience of many countries, in particular Norway, and recently also oil rich states in the US, these mechanisms seem unable to capture the experiences of resource abundance very well. As we argued, it seems more likely that resource abundance has been a blessing for productivity and aggregate income. To discuss this, we now turn to the analysis that constitutes the main innovation of our paper, where we discuss increased oil activity and incorporate the resource movement effects that stem from this.

5.2 Increased Oil Activity

When oil activity increases it follows from (27) that

$$\frac{\frac{d\gamma^*}{\gamma^*}}{dR^*} = -\frac{1}{R^*} < 0.$$

From (28) we find

$$\frac{\frac{d\lambda^*}{\lambda^*}}{dR^*} = -\frac{Q^*}{(1-\sigma)\,(g+Q^*R^*)} < 0.$$

It follows that in the new dynamic equilibrium, the level of productivity in the traded sector is lower relative to the level of productivity in both the oil service industry and the non-traded sector.

Moreover, from the above two equations we can also find that if

$$\sigma < \frac{g}{g+Q^*R^*},$$

then the relative decline of λ^* exceeds the relative decline of γ^*, and productivity will have increased in the oil service sector relative to that in the non-traded sector, while the opposite will hold true if this condition is not fulfilled.

In terms of Figure 5, the curves for $\dot{\lambda}_t = 0$ and $\dot{\gamma}_t = 0$ both shift down. As seen from the figure, after the rise in oil activity productivity growth in both the oil service industry and the non-traded sector exceeds productivity growth in the traded sector, and λ_t and γ_t both decrease over time. In the new dynamic equilibrium λ^* and γ^* are both at a lower level than initially.

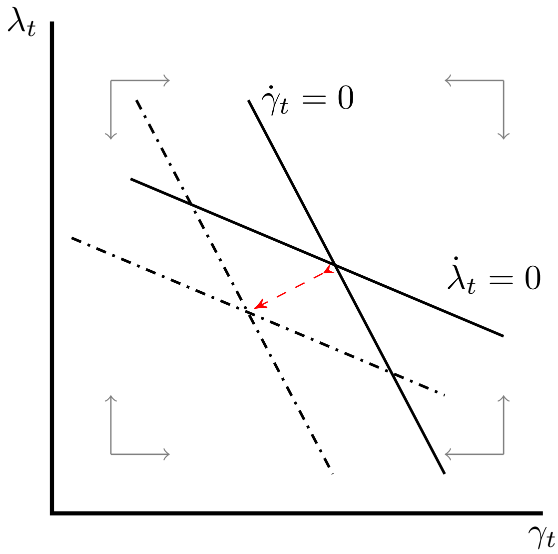

Figure 5. Phase diagram 3. Transitional dynamics and steady state effects of increased oil activity.

To see the intuition behind these transitional dynamics, note (from the static model) that when oil activity increases, employment in the oil service sector goes up, while employment in the traded sector is reduced. Thus productivity growth in the oil service sector exceeds that in the traded sector, and γ_t falls over time. Employment in the non-traded sector may increase or decrease, but because of the fall in employment in the traded sector, productivity growth, independently of this, shifts in favour of the non-traded sector compared to the traded sector.

5.2.1 Higher oil activity and the level of productivity and income

Here we investigate once again the consequences for transitional productivity dynamics and, by implication, the levels of sectoral productivities and production in the new steady state. Note also that in this case, all sectoral employment levels have transitioned back to their initial levels in the new steady state. (This follows first as n^* is independent of R^*, and second because of (27) from which $\gamma^* R^*$, and therefore steady state employment in the oil service sector is also independent of R^*. From these two observations it follows that employment in the traded sector must also be back at its initial steady state level.) Therefore, if growth in productivity along transitional paths differs from that in the steady state, it again would imply that the *level* of production in the new steady state is also different compared to that in the initial steady state. Thus, the implications for sectoral steady state production levels can, again, be backed out from the transitional dynamics of the model.

To see the main contrast with the case of an increased oil price above, note that the transition to the new steady state starts out with $\gamma_t R^* > \gamma^* R^*$. This implies that, in contrast to the case with an increased oil price analyzed above, the employment level in the oil service industry now starts out higher along the transition path than its value in the steady state. Moreover, as seen in Figure 5, when there are no oscillatory dynamics, employment in the oil service sector is higher throughout the transition. This follows inasmuch as when $\dot{\gamma}_t < 0$, then employment in the oil service sector will monotonically be falling over time until the new steady state emerges. However, since employment in the oil service sector started out at a higher level at the start of transition, then it must also be higher all along the transition path.

Employment in the traded sector initially falls, but with time returns to its steady state value. Again, looking at Figure 5 where there are no oscillatory dynamics, then employment in the traded sector is lower throughout the transition. To see this, assume, to obtain a contradiction, that at some point employment is higher than in the steady state. Then, since $\dot{\lambda}_t < 0$, from (17) we have it that employment in the non-traded sector is also higher than its steady state value. But again, this implies a contradiction, since we have already shown that employment in the oil service sector is higher than in the steady state, and employment in all sectors cannot simultaneously exceed their steady state values. Ergo, in this case, employment in the traded sector during transition, is lower than its steady state value. Finally, employment in the non-traded sector may go both ways, but should it fall, it will initially fall by less than the fall in employment in the traded sector (again since the transition starts at $\dot{\lambda}_t < 0$).

Consider again the case where indirect learning spillovers are negligible. Note that, in contrast to the above case of the increased oil price, productivity growth in the oil service sector now starts from a *higher* level than its steady state level. Thus, while the dynamic resource movement effect contributed to *lower* productivity growth in an environment with a higher oil price, it contributes to *higher* productivity growth in an environment of increased oil activity. If learning in the oil service industry is strong, and if there are strong learning spillovers to other sectors, higher oil extraction may have exactly the opposite effect on aggregate income compared to a higher oil price. The oil service sector may be an engine of growth and income creation when oil activity increases. Nevertheless, it may contribute to the opposite when the oil price increases.

This is exactly the opposite result of van Wijnbergen (1984), Krugman (1987) and Sachs and Warner (1995). In their models, more oil leads to less employment in the traded sector; however, since they do not have a resource movement effect and assume that only the traded sector generates learning by doing, productivity growth and productivity levels will always end up lower with more oil. In contrast, since we incorporate the resource movement effect, we find increased learning from the oil service sector which very likely will spill over into other sectors, turning the standard Dutch disease result on its head.[9]

We have now seen how our model delivers new results compared to the existing literature on learning by doing and the Dutch disease. In particular, this is so for income and productivity levels. The impact on these will differ depending on whether increased oil income arrives through a higher oil price or through higher oil activity. We now turn to an empirical analysis of these issues.

[9] Our model also has different real exchange rate dynamics compared to these models, and this is discussed in Appendix B.

6 Empirical implications and results

The main empirical implications from the theory model are simple and intuitive: the impacts of an oil boom will differ depending on whether the increased oil income arrives by way of a higher oil price or higher oil activity. In the first case the resource movement effect is likely to pull in the direction of lower productivity, while in the latter case the resource movement effect is likely to pull in the direction of higher productivity. Thus, following unexpected oil price innovations, we should expect to see only minor and relative stable cross-sectional differences across time in the productivity levels in oil service industries relative to non-traded sectors. On the other hand, following unexpected oil activity innovations the cross sectional productivity levels in oil-service industries should increase more than in non-traded sectors. Moreover, if the size of the oil service sector has grown over time, it would be natural for the learning effect to increase. Thus, and in line with the model prediction, we expect to see stronger productivity differentials between the oil-service and non-traded sectors today, than for example in the 1980s.

To examine these predictions empirically, we proceed in two steps. First, we construct structural shocks using a time varying VAR framework, then we use the (structural) oil price and oil activity shocks derived in the first step and regress them on the productivity developments in the various sectors.

The VAR model can be written as

$$y_t = B_{1,t}y_{t-1} + \cdots + B_{p,t}y_{t-p} + A0_t^{-1}\Sigma_t\epsilon_t \tag{29}$$

where y_t is a 3×1 vector of observed endogenous variables containing quarterly data on world activity (G_t), the real price of oil (Q_t) and value added in the petroleum sector (R_t). To allow for the fact that the variances and dynamic multipliers of the structural shocks might change across time, the VAR model allows for time-varying parameters and stochastic volatility. In particular, $B_{p,t}$ are 3×3 matrices containing time varying coefficients on the lags of the endogenous variables, where the number of lags is set to $p = 2$. We work with the convention that $\epsilon_t \sim i.i.d.N(0, I)$ such that the reduced form covariance matrix of (29), denoted by Ω_t, can be decomposed as follows

$$A0_t\Omega_t A0_t' = \Sigma_t\Sigma_t' \tag{30}$$

where $A0_t$ and Σ_t is a lower triangular matrix and a diagonal matrix, respectively

$$A0_t = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ ao_{21,t} & 1 & \ddots & 0 \\ \vdots & \ddots & \ddots & \vdots \\ ao_{q1,t} & \cdots & ao_{qq-1,t} & 1 \end{bmatrix} \quad \Sigma_t = \begin{bmatrix} \sigma_{1,t} & 0 & \cdots & 0 \\ 0 & \sigma_{2,t} & \ddots & 0 \\ \vdots & \ddots & \ddots & \vdots \\ 0 & \cdots & 0 & \sigma_{q,t} \end{bmatrix} \tag{31}$$

This decomposition of the covariance matrix Ω_t builds on the work of Primiceri (2005), and facilitates identification of the model's structural shocks, ϵ_t, and their associated time varying volatility, captured by Σ_t. In particular, the lower triangular structure of

$A0_t$ means that we can identify the structural shocks using a simple recursive identification scheme. Finally, the model's time varying parameters and stochastic volatilities are assumed to follow random walk processes. In the interest of brevity, technical details about model specification and estimation are given in Appendix D.

The choice of variables builds on common findings in the oil-macro literature, and the identification strategy builds on Bjørnland and Thorsrud (2016). The variables are included in the system in the order; G, Q and R, allowing us to identify three structural shocks using the Cholesky decomposition: a global activity shock (ϵ_t^G); an oil price shock (ϵ_t^Q); and a resource (oil) activity shock (ϵ_t^R). The vector with structural disturbances is defined as:

$$\epsilon_t = [\epsilon_t^G, \epsilon_t^Q, \epsilon_t^R]'. \tag{32}$$

Accordingly, we restrict global activity to respond to oil price disturbances with a lag (one quarter). This restriction is consistent with the sluggish behavior of global economic activity after each of the major oil price hikes in recent decades, see e.g., Hamilton (2009). Furthermore, we do not treat oil prices as exogenous to the rest of the global macro economy. Instead, any unexpected news regarding global activity can affect real oil prices contemporaneously. This is consistent with recent work in the oil market literature, such as Kilian (2009), Lippi and Nobili (2012), and Aastveit et al. (2015). In contrast to these papers, and to keep our empirical model as parsimonious as possible, we do not explicitly identify a global oil supply shock.[10]

Turning to the resource activity shocks, in the very short run, disturbances originating in the Norwegian continental shelf cannot affect global activity and the price of oil. These are plausible assumptions insofar as Norway is a small, open economy. However, resource activity responds to unexpected disturbances in global activity and the real oil price on impact. Norway is an oil exporter, and any disturbances affecting the real price of oil will have an almost immediate effect both on the demand and supply sides of the economy.

To trace the effects of oil price and oil activity shocks on productivity levels across a broad range of sectors in the economy we use linear projections (Jordà (2005)). In particular, we use the structural shocks derived from the VAR and regress these on sectoral specific productivity developments according to

$$\Delta H_{i,t:t+h} = \beta_{i,0,h} + \beta_{i,h}\epsilon_t^j + u_{i,t} \tag{33}$$

where $\Delta H_{i,t:t+h}$ is the cumulative growth in labour productivity in sector i over h time periods, and ϵ_t^j the structural shock with $j = Q, R$. The parameter of interest is $\beta_{i,1}$, which yields the impulse response function for the level of $H_{i,t:t+h}$ at horizon h. Estimation is done individually for each sector and with a rolling estimation window of 50 observations. The first estimation sample covers the period 1985:Q2 - 1997:Q3 while the last sample considered covers the period 2008:Q4 - 2016:Q2.

[10] However, as shown in Kilian (2009), and a range of subsequent papers, such supply shocks explain a trivial fraction of the total variance in the price of oil, and do not account for a large fraction of the variation in real activity either.

In terms of data, we measure global activity using the year-on-year quarterly growth rate in G7 aggregate industrial production, collected from Reuters Datastream. From the same source we obtain the Brent Blend nominal oil price, which we then deflate by U.S. core CPI and transform into yearly growth rates. Norwegian oil activity is measured by value added in the Norwegian petroleum sector, excluding services.[11] This variable is collected from Statistics Norway, but as above, we transform it into yearly growth rates.

Sectoral (labour) productivity indicators are constructed using data for value added and employment statistics collected from the quarterly *National Account Statistics* published by Statistics Norway. In particular, for each sector we measure the growth rate in productivity as the difference between the growth rate in value added and the growth rate in employment. Cumulative growth rates for a given h are constructed accordingly.

There are no formal definitions of what are referred to as traded and non-traded sectors. In the following we categorize all sectors belonging to the oil sector and the manufacturing sector as *Oil-Traded*, and all sectors not belonging to this cluster as *Non-Traded*. In total 33 sectors are included in the analysis. Of these, 17 are classified as belonging to the *Oil-Traded* segment. See Table 1 in the Appendix for further details.

6.1 Empirical results

Below we examine the dynamic responses to the oil activity and the oil price shock on productivity in a resource rich economy such as Norway.[12] We start by estimating a simpler constant parameter version of (29) to derive the structural shocks, and use the whole sample period (1985:Q2 - 2016:Q2) when estimating (33). As such, Figure 6 highlights our main empirical findings, using a box plot to illustrate the three year ahead productivity responses across traded and non-traded sectors following an oil price shock and a resource activity shock.

First, comparing the effects of an oil activity and an oil price shock, we find that the effect of an oil activity shock increases productivity across nearly all industries. This is in contrast to the oil price shock which has virtually zero effect on productivity across all sectors. Second, the positive effect of the oil activity shock is largest for the traded sector. This is in contrast to the main predictions from the Dutch disease models, according to which productivity in the traded sector should fall, but fully in line with the theoretical model proposed here.

Having noted that the average responses to the oil activity shocks are positive, it is natural to ask whether the productivity responses to the oil boom have increased over time, and whether the role played by the traded sector is more important now than

[11] We exclude services from our measure of oil activity because services are part of the sectoral responses we are interested in analyzing. That is, we do not want our oil activity shock to capture unexpected shocks to the service sector itself.

[12] In unreported results we confirm the impulse responses implied by the VAR model are well in line with existing knowledge from the oil market literature. That is, following a global activity shock, oil prices increase significantly as demand for resources for production goes up. Conversely, following an oil price shock, global activity growth fall, albeit with a small lag.

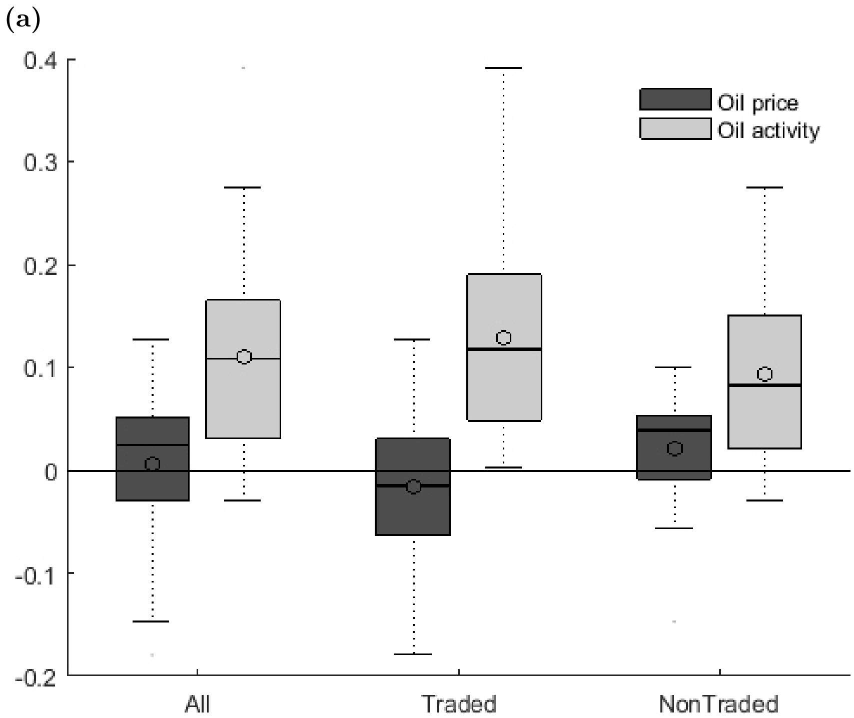

Figure 6. Oil price and oil activity shocks and productivity responses across industries. The boxes report the inter-quantile range across the sectors. The vertical lines are the median estimates while the circles are the mean estimates. The dotted lines with bars are the outliers.

before in explaining this increased productivity growth. To answer these questions we turn to the time varying version of (29), and estimate the local linear projections using a rolling estimation window, as described above. Figures 7 and 8 summarize the results. In particular, Figure 7 graphs a box plot of the one year ahead productivity responses across different industries and time to a one-standard-deviation structural shock in oil prices, while Figure 8 displays the responses in the same variables to a one-standard-deviation structural shock in oil activity (oil boom). In both figures, we graph the responses for productivity (value added pr worker) in the traded industries (top panel), the non-traded industries (middle panel) and the whole economy (lower panel). The dotted red line is the mean response across time.

We start by analysing the effects of an oil price shock. As expected, and consistent with our earlier results, we do not find any large scale productivity spillovers to either sector, see Figure 7. There is a small upward sloping trend in the response pattern across time, at least when considering the whole economy, but a large fraction of the industries are either unaffected or negatively affected by the oil price shock even towards the end of the sample. Hence, models that focus solely on windfall gains due to increased spending potential from higher oil prices, would likely conclude that the resource sector can not be an engine of growth.

However, as shown by our theory, if the learning effects in the oil service sector are strong, productivity growth in the oil service sector may exceed the steady state level considerably, and the oil service sector may be an engine of growth and overall income creation. This is what we see in Figure 8. The figure highlights that a shock to oil activity,

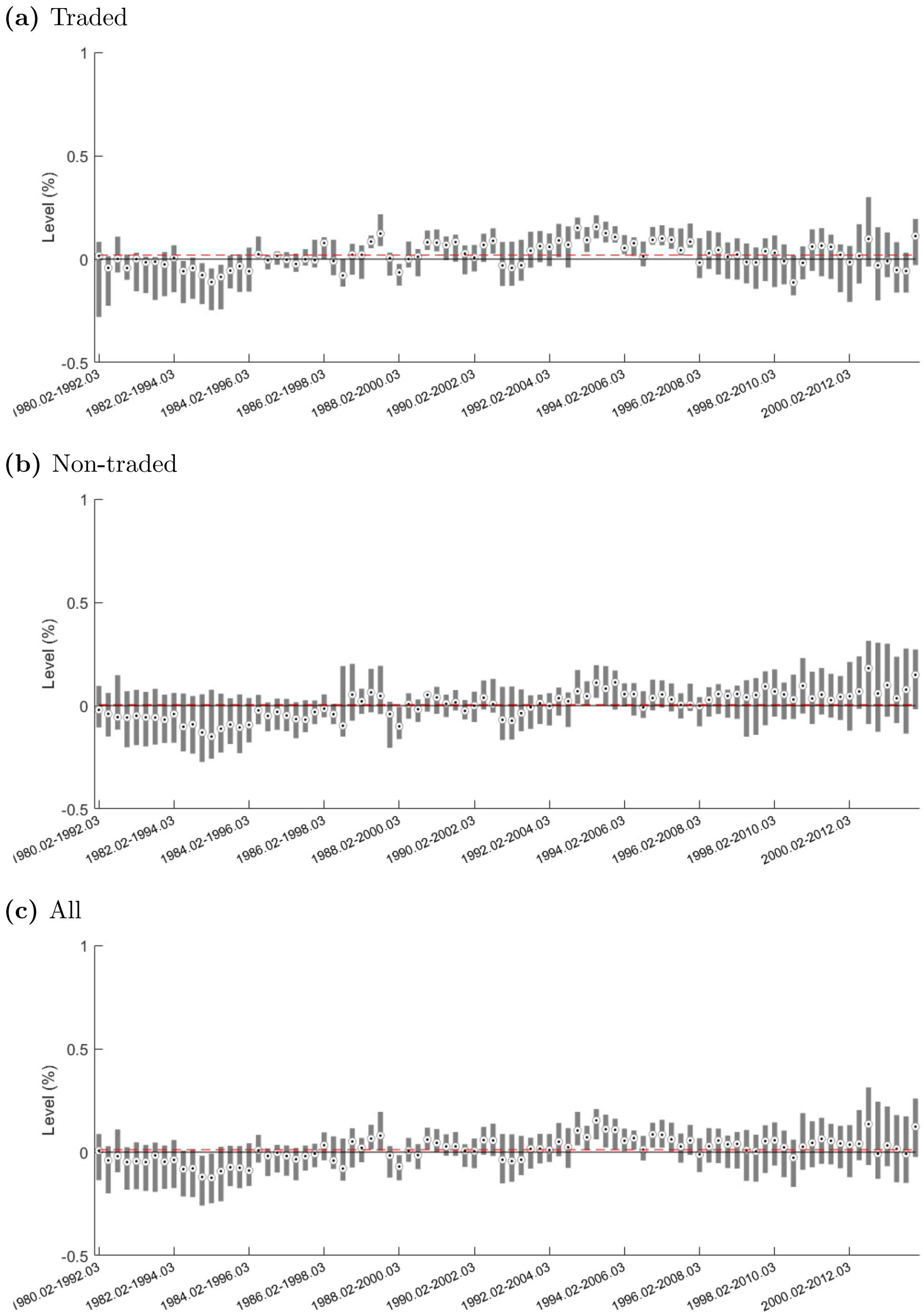

Figure 7. Oil price shock and productivity responses across industries and time. The boxes report the inter-quantile range across the sectors. The circles inside each box is the median estimate. The dotted red line is the mean response across time. The response horizon is one year.

due to, say, a new discovery or increased extraction of oil, lift productivity levels in the whole economy (lower panel). Over the whole sample, the average response coefficients are positive, as in Figure 6. Nevertheless, the coefficients also drift sharply up around the start of the millennium, suggesting knowledge accumulation over time. Behind the elevated productivity level is the highly productive oil service industry, as clearly seen in the top panel. During two distinct oil cycles - the mid 1990s and from 2001 on - productivity growth in the traded industry was an engine for growth. Finally, the results also suggest

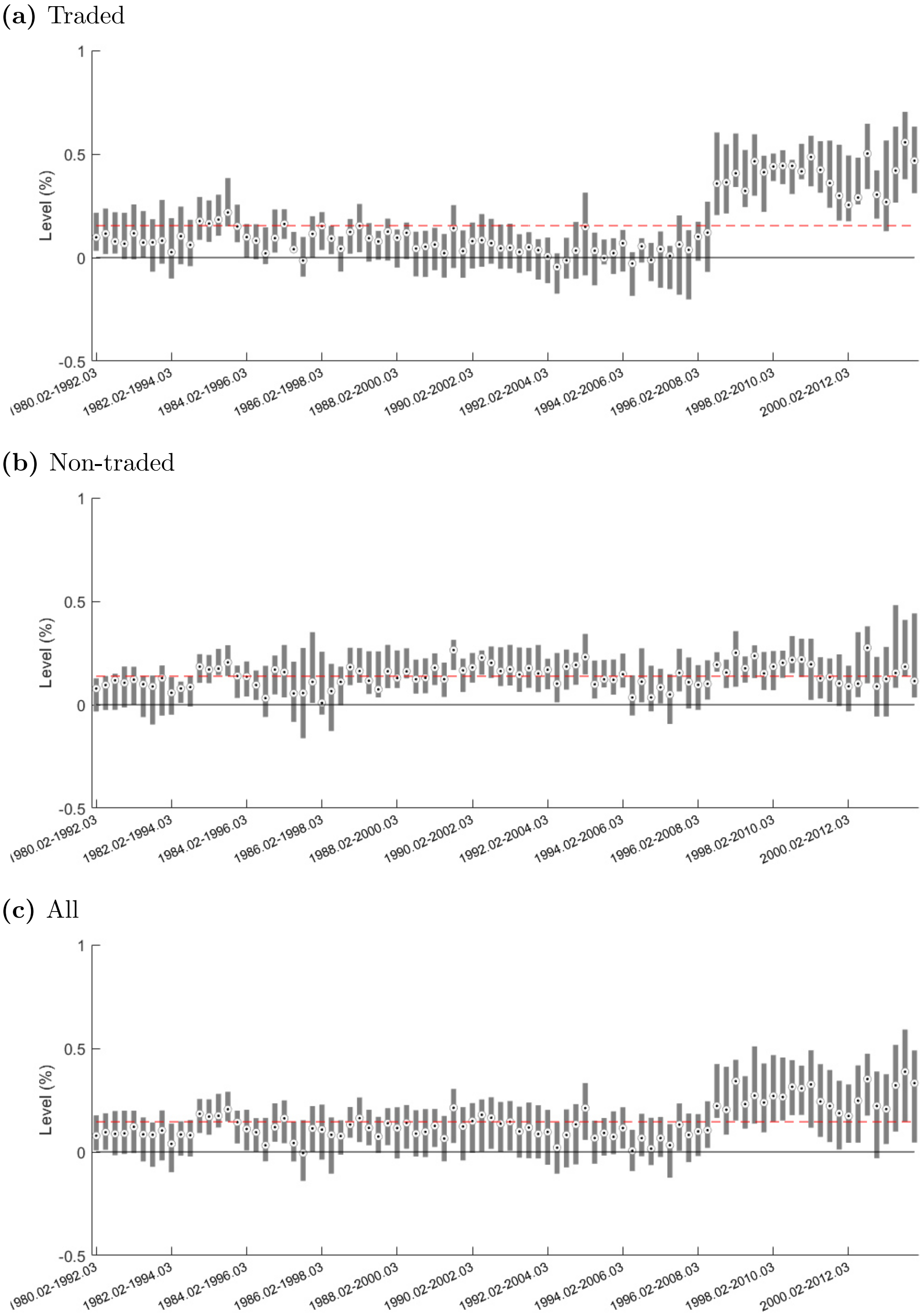

Figure 8. Oil activity shock and productivity responses across industries and time. The boxes report the inter-quantile range across the sectors. The circles inside each box is the median estimate. The dotted red line is the mean response across time. The response horizon is one year.

the creation of knowledge by interaction with the non-traded industries: increased activity in the oil sector pushes up productivity in the non-traded sector throughout the sample (middle panel). Therefore, and in contrast to the predictions of the traditional Dutch disease literature, value added per worker in the overall economy increased with the oil boom, insofar as learning by doing in the oil-traded industries spills over into the other industries.

In sum, these empirical findings are very much in line with the predictions given by the theoretical model proposed in this paper. We have shown that the productivity responses in the overall economy tend to be positive following unexpected oil activity shocks, and that this effect seems to grow stronger over time. In contrast, following an oil price shock, neither of these effects materialize.

7 Conclusion

We extend the literature of resource rich economies by developing a dynamic three sector model to incorporate productivity dynamics in all sectors, and to incorporate the productivity dynamics from the spending as well as the resource movement effect. We show that this dramatically alters the conclusions derived from earlier models of learning by doing and the Dutch disease. In particular, the resource movement effect implies that the growth effects of natural resources are likely to be positive, turning around previous growth results in the literature relying on the spending effect.

The model is applied to a major oil producer, in this case Norway. We show that a resource boom resulting from increased oil activity, also increases productivity significantly in other industries, including manufacturing. Hence, value added per worker in the economy is increasing with the oil boom, as there is learning by doing in the oil service industries that spills over to the other industries. As the oil related industries have gained experience and become a more important part of the economy, these productivity effects have increased as well. We find no such productivity spillovers following an oil price shock. Hence, models focusing on windfall gains due to an increased spending potential created by higher oil prices would incorrectly conclude that the resource sector can not be an engine of growth.

References

Aastveit, K. A., H. C. Bjørnland, and L. A. Thorsrud (2015). What drives oil prices? Emerging versus developed economies. *Journal of Applied Econometrics 30*(7), 1013–28.

Allcott, H. and D. Keniston (2018). Dutch Disease or Agglomeration? The Local Economic Effects of Natural Resource Booms in Modern America. *Review of Economic Studies (Forthcoming).*

Beine, M., S. Coulombe, and W. N. Vermeulen (2015). Dutch disease and the mitigation effect of migration: evidence from Canadian provinces. *The Economic Journal 125*(589), 1574–1615.

Bjørnland, H. C. and L. A. Thorsrud (2016). Boom or gloom? Examining the Dutch disease in two-speed economies. *The Economic Journal 126*(598), 2219–2256.

Boschini, A. D., J. Pettersson, and J. Roine (2007). Resource curse or not: A question of appropriability. *Scandinavian Journal of Economics 109*(3), 593–617.

Bruno, M. and J. Sachs (1982a). Energy and resource allocation: a dynamic model of the "Dutch Disease". *The Review of Economic Studies 49*(5), 845–859.

Bruno, M. and J. Sachs (1982b). Input price shocks and the slowdown in economic growth: the case of UK manufacturing. *The Review of Economic Studies 49*(5), 679–705.

Carter, C. K. and R. Kohn (1994). On Gibbs Sampling for State Space Models. *Biometrika 81*(3), 541–553.

Charnavoki, V. and J. Dolado (2014). The Effects of Global Shocks on Small Commodity-Exporting Economies: Lessons from Canada. *American Economic Journal: Macroeconomics 6*(2), 207–237.

Corden, W. M. (1984). Booming sector and Dutch disease economics: Survey and consolidation. *Oxford Economic Papers 36*(3), 359–380.

Corden, W. M. and J. P. Neary (1982). Booming sector and de-industrialisation in a small open economy. *The Economic Journal 92*(368), 825–848.

Del Negro, M. and G. E. Primiceri (2015). Time Varying Structural Vector Autoregressions and Monetary Policy: A Corrigendum. *Review of Economic Studies 82*(4), 1342–1345.

Feyrer, J., E. T. Mansur, and B. Sacerdote (2017). Geographic dispersion of economic shocks: Evidence from the fracking revolution. *American Economic Review 107*(4), 1313–1339.

Gilje, E., R. Ready, and N. Roussanov (2016). Fracking, drilling, and asset pricing: Estimating the economic benefits of the shale revolution. NBER working paper no. 22914, National Bureau of Economic Research.

Gylfason, T., T. T. Herbertsson, and G. Zoega (1999). A mixed blessing. *Macroeconomic Dynamics 3*(2), 204–225.

Hamilton, J. D. (2009). Causes and consequences of the oil shock of 2007-08. *Brookings Papers on Economic Activity 40*(1), 215–283.

Jordà, s. (2005). Estimation and Inference of Impulse Responses by Local Projections. *American Economic Review 95*(1), 161–182.

Kilian, L. (2009). Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market. *American Economic Review 99*(3), 1053–69.

Kim, S., N. Shephard, and S. Chib (1998, July). Stochastic Volatility: Likelihood Inference and Comparison with ARCH Models. *Review of Economic Studies 65*(3), 361–93.

Krugman, P. (1987). The narrow moving band, the Dutch disease, and the competitive consequences of Mrs. Thatcher: Notes on trade in the presence of dynamic scale economies. *Journal of Development Economics 27*(1), 41–55.

Leong, W. and K. Mohaddes (2011). Institutions and the volatility curse. Mimeo, University of Cambridge.

Lippi, F. and A. Nobili (2012). Oil and the macroeconomy: A quantitative structural analysis. *Journal of the European Economic Association 10*(5), 1059–1083.

Matsen, E. and R. Torvik (2005). Optimal Dutch disease. *Journal of Development Economics 78*(2), 494 – 515.

Mehlum, H., K. Moene, and R. Torvik (2006). Institutions and the Resource Curse. *The Economic Journal 116*(508), 1–20.

Primiceri, G. E. (2005). Time varying structural vector autoregressions and monetary policy. *The Review of Economic Studies 72*(3), 821–852.

Rauch, J. E. (1997). Balanced and unbalanced growth. *Journal of Development Economics 53*(1), 41–66.

Robinson, J. A., R. Torvik, and T. Verdier (2017). The political economy of public income volatility: with an application to the resource curse. *Journal of Public Economics 145*, 243–252.

Sachs, J. D. and A. M. Warner (1995). Natural resource abundance and economic growth. Working papers 5398, National Bureau of Economic Research.

Torvik, R. (2001). Learning by doing and the Dutch disease. *European Economic Review 45*(2), 285–306.

van der Ploeg, F. and S. Poelhekke (2009). Volatility and the natural resource curse. *Oxford Economic Papers 61*(4), 727–760.

van der Ploeg, F. and A. J. Venables (2011). Harnessing windfall revenues: Optimal policies for resource-rich developing economies. *The Economic Journal 121*(551), 1–30.

van der Ploeg, F. and A. J. Venables (2013). Absorbing a windfall of foreign exchange: Dutch disease dynamics. *Journal of Development Economics 103*, 229 – 243.

van Wijnbergen, S. (1984). The "Dutch Disease": a disease after all? *The Economic Journal 94*(373), 41–55.

Weber, J. G. (2012). The effects of a natural gas boom on employment and income in Colorado, Texas, and Wyoming. *Energy Economics 34*(5), 1580–1588.

Appendices

Appendix A Additional Dynamics

In this appendix we show that when the curve for $\dot{\lambda}_t = 0$ slopes upwards then the steady state effects and the transitional dynamics are essentially the same as those we analyzed in the main text.

The phase diagram is now shown in Figure 9a. Again, above the curve for $\dot{\lambda}_t = 0$, λ_t is falling over time, while below the curve, λ_t is growing over time. To the left of the curve for $\dot{\gamma}_t = 0$, γ_t is increasing over time, and to the right of the curve γ_t is falling over time.

As in the main text, higher oil prices shift both curves down in such a way that the steady state value of γ^* is unchanged, while the steady state value of λ^* falls. This is depicted in Figure 9b, and as the arrows indicate, the transitional dynamics when there are no oscillatory dynamics are the same as those in Figure 4 in the main text. The rest of the analysis also remains unaffected.

The effects of higher oil activity are shown in Figure 9c. As in the main text both the curve for $\dot{\lambda}_t = 0$ and for $\dot{\gamma}_t = 0$ shift downwards in such a way the steady state levels of λ^* and γ^* also fall. And as seen, the transitional dynamics without oscillatory dynamics are the same as those in Figure 5 in the main text, so that and in this case, too, the rest of the analysis remains unaffected.

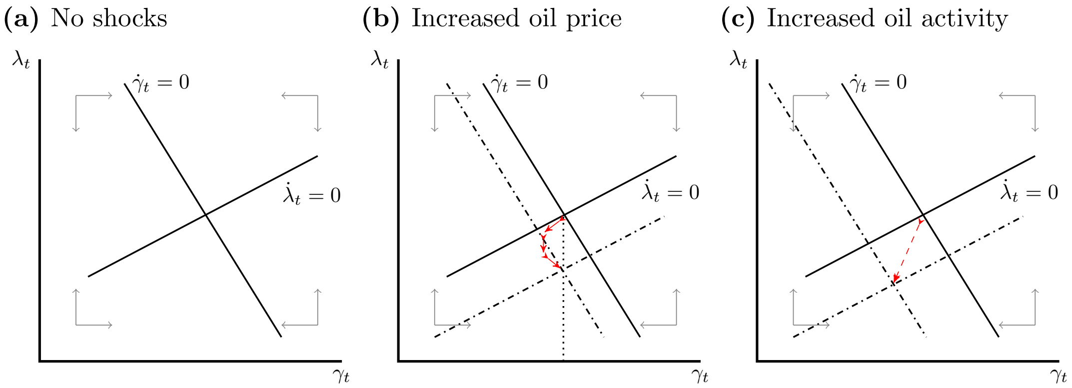

Figure 9. Phase diagrams when the curve for $\dot{\lambda}_t = 0$ is upward sloping.

Appendix B Real Exchange Rate Dynamics

In the main analysis, we found that in the short run the real exchange rate appreciated in the standard fashion, both in the case of increased oil price, and in that of increased oil activity. Note, however, that in the new dynamic equilibrium the real exchange rate has, in both cases, depreciated also compared to the level it had before the higher oil price or the higher oil activity. To see this, note from (10) that we have that the steady state real

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exchange rate given by

$$P^* = \frac{g'\left(1 - n^* - \alpha\gamma^* R^*\right)}{f'(n^*)}\lambda^*.$$

Inserting for $\gamma^* R^*$ from (27), and from $\lambda^* = \lambda^*(Q^* R^*)$, we get

$$P^* = \frac{g'\left(1 - n^* - \alpha\frac{u(1-\delta_N)n^*}{q\alpha(1-\delta_S)}\right)}{f'(n^*)}\lambda^*(Q^* R^*).$$

Noting that $\frac{d\lambda^*(Q^* R^*)}{dQ^*}$ and $\frac{d\lambda^*(Q^* R^*)}{dR^*}$ are both negative, it follows that

$$sign\frac{dP^*}{dQ^*} = sign\frac{dP^*}{dR^*} < 0.$$

The intuition for these results is the following. After the initial real exchange rate appreciation, productivity growth in the traded sector falls short of productivity growth in the other sectors. Thus a dynamic Balassa-Samuelson effect operates, in which the real exchange rate starts to depreciate. In the new steady state, relative productivity is permanently shifted away from the traded sector and towards the non-traded sector, and thus we have permanently depreciated the real exchange rate as compared to its initial value. Note the contrast between this result and two standard alternative results. The first such standard result shows that with decreasing returns to scale in production, then we get a permanent appreciation of the real exchange rate when oil income increases. The second such standard result is that with constant returns to scale in production in the long run, the initial appreciation is followed by a depreciation that brings the real exchange rate exactly back to its initial level. The reason for the different result in the present model is that although we have static decreasing returns to scale, we have dynamic increasing returns to scale.

Appendix C Data

Table 1. Sectors and classification.

Name	Traded
Oil and gas extraction	true
Service activities incidental to oil and gas	true
Food products, beverages and tobacco	true
Textiles, wearing apparel, leather	true
Manufacture of wood and wood products, except furniture	true
Manufacture of paper and paper products	true
Printing and reproduction of recorded media	true
Refined petroleum, chemical and pharmaceutical products	true
Rubber, plastic and mineral products	true
Basic metals	true
Machinery and other equipment n.e.c	true
Building of ships, oil platforms and moduls	true
Furniture and other manufacturing n.e.c	true
Repair and installation of machinery and equiment	true
Electricity, gas and steam	false
Water supply, sewerage, waste	false
Construction	false
Wholesale and retail trade, repair of motor vehicles	false
Transport via pipelines	false
Ocean transport	false
Transport activities excl. ocean transport	false
Postal and courier activities	false
Accommodation and food service activities	false
Information and communcation	false
Financial and insurance activities	false
Real estate activities	false
Imputed rents of owner-occupied dwellings	false
Professional, scientific and and technical activities	false
Administrative and support service activities	false
Public administration and defence	false
Education	false
Health and social work	false
Arts, entertainment and other service activities	false

Appendix D TVP VAR, priors and estimation

The time varying parameter VAR used in Section 6 is standard, and follows the setup introduced by Primiceri (2005). Here we describe in brief the full model structure, the prior choices, and the MCMC based estimation algorithm. For details about the estimation algorithm we refer to Primiceri (2005).[13]

For convenience, we repeat the VAR model here

$$y_t = B_{1,t}y_{t-1} + \cdots + B_{p,t}y_{t-p} + A0_t^{-1}\Sigma_t\epsilon_t \tag{34}$$

where y_t is a $N \times 1$ vector of observed endogenous variables, $B_{p,t}$ the time varying dynamic coefficients, $A0_t^{-1}$ the structural impact matrix, and ϵ_t the structural shock vector with associated covariances matrix Σ_t.

We work with the convention that $\epsilon_t \sim i.i.d.N(0, I)$ such that the reduced form covariance matrix of (34), denoted by Ω_t, can be decomposed as follows

$$A0_t\Omega_t A0_t' = \Sigma_t\Sigma_t' \tag{35}$$

where $A0_t$ and Σ_t are a lower triangular matrix and a diagonal matrix, respectively

$$A0_t = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ ao_{21,t} & 1 & \ddots & 0 \\ \vdots & \ddots & \ddots & \vdots \\ ao_{q1,t} & \cdots & ao_{qq-1,t} & 1 \end{bmatrix} \quad \Sigma_t = \begin{bmatrix} \sigma_{1,t} & 0 & \cdots & 0 \\ 0 & \sigma_{2,t} & \ddots & 0 \\ \vdots & \ddots & \ddots & \vdots \\ 0 & \cdots & 0 & \sigma_{q,t} \end{bmatrix} \tag{36}$$

The model's time-varying parameters and stochastic volatilities are assumed to follow independent random walk processes. In particular, for a single element in each of the time varying parameter matrices we assume

$$b_t = b_{t-1} + w_t \tag{37a}$$

$$ao_t = ao_{t-1} + s_t \tag{37b}$$

$$h_t^\sigma = h_{t-1}^\sigma + q_t \tag{37c}$$

where $h_t^\sigma = log(\sigma_t)$.

All the errors in the model are assumed to be jointly normally distributed, such that

$$V = var\left(\begin{bmatrix} \epsilon_t \\ w_t \\ s_t \\ q_t \end{bmatrix}\right) = \begin{bmatrix} I_N & 0 & 0 & 0 \\ 0 & W & 0 & 0 \\ 0 & 0 & S & 0 \\ 0 & 0 & 0 & Q \end{bmatrix} \tag{38}$$

[13] Note here that we use the updated estimation algorithm, as documented in Del Negro and Primiceri (2015).

Here, as already indicated above, I_N is a $N \times N$ identity matrix, and Q is a $N \times N$ diagonal matrix. W and S are assumed to be block diagonal matrices

$$W = \begin{bmatrix} W_1 & 0 & \cdots & 0 \\ 0 & W_2 & \ddots & 0 \\ \vdots & \ddots & \ddots & \vdots \\ 0 & \cdots & 0 & W_N \end{bmatrix} \quad S = \begin{bmatrix} S_1 & 0 & \cdots & 0 \\ 0 & S_2 & \ddots & 0 \\ \vdots & \ddots & \ddots & \vdots \\ 0 & \cdots & 0 & S_{q-1} \end{bmatrix} \tag{39}$$

where W_i for $i = 1, \ldots, N$ is a $m \times m$ matrix, with $m = N(p+1)$, and S_1 is a 1×1 matrix, S_2 is a 2×2 matrix, and so on.[14].

The model's unknown hyper-parameters are collected in V, and are W, S, and Q. The model's latent state variables are $B_t = [B_{1,t}, \ldots, B_{p,t}]$, $A0_t$, and Σ_t, where we let $B = [B_1, \ldots, B_T]'$, $A0 = [A0_1, \ldots, A0_T]'$, and $\Sigma = [\Sigma_1, \ldots, \Sigma_T]'$, denote the whole history of all the state variables. Likewise, we write $Y = [y_1, \ldots, y_T]'$. Estimation of the model is conducted using a Gibbs sampler, sequentially drawing the model's unobserved state variables and hyper-parameters utilizing 4 blocks until convergence is achieved. In essence, each block involves exploiting the state space nature of the model using the Kalman Filter and the simulation smoother suggested by Carter and Kohn (1994).

First, conditional on $A0$ and Σ the model in (34) together with the transition equation in (37a) becomes a Gaussian linear state space model, and the posterior distribution of B can be sampled using a standard simulation smoother. Next, and for the same reasons, conditional on B and Σ we can sample $A0$ using (34) and (37b). Drawing Σ, conditional on $A0$ and B, is somewhat more involved since it consists of transforming a nonlinear and non-Gaussian state space system into a linear and approximately Gaussian one. Here we do so by following Kim et al. (1998), which again allows us to use a standard simulation smoother. Finally, simulating the conditional posterior of V is simple, since it is the product of independent inverse-Wishart distributions.

To initiate the MCMC sampling algorithm we need priors for the model's hyper-parameters as well as starting values (time zero) for the latent states. Here we follow the time varying VAR literature closely, and set

$$\begin{aligned} B_0 &\sim N(\hat{B}_{OLS}, 4 \cdot V(\hat{B}_{OLS})) \\ A0_0 &\sim N(\hat{A0}_{OLS}, 4 \cdot V(\hat{A0}_{OLS})) \\ h_0^\sigma &\sim N(\hat{h}_{OLS}^\sigma, I) \\ W &\sim IW(k_w^2 \cdot 40 \cdot V(\hat{B}_{OLS}), 40) \\ Q &\sim IW(k_q^2 \cdot 10 \cdot I_N, 10) \\ S_1 &\sim IW(k_s^2 \cdot 2 \cdot V(\hat{A0}_{1,OLS}), 2) \\ S_2 &\sim IW(k_s^2 \cdot 3 \cdot V(\hat{A0}_{1,OLS}), 3) \end{aligned}$$

Here, the OLS subscript denotes the estimates obtained from estimating the model using ordinary least squares on the first 20 years of data. $k_w = 0.01$, $k_q = 0.01$, and $k_s = 0.1$.

[14]That is, S_1 is associated with $ao_{21,t}$ in (36), S_2 is associated with $ao_{31,t}$ and $ao_{32,t}$ in (36), etc.

Set in this way, the priors are not flat, but rather diffuse and uninformative (Primiceri (2005)).