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**Abstract:** We study how monetary policy should respond to shocks which permanently alter the steady state structure of the economy. In such a case monetary policy affects not only the short run misallocations due to nominal rigidities, but also relative prices which stimulate reallocation of capital. We consider a permanent and negative shock to export revenues that requires a larger traded sector and a smaller non-traded sector in the new steady state. This reallocation calls for a change in relative prices during the transition, but may also lead to a period of high unemployment. We show how an appropriate monetary policy could mitigate the welfare costs of the transition by allowing the exchange rate to depreciate, and thereby allowing inflation to increase in the short run. Traditional monetary policy regimes, such as inflation targeting or a fixed exchange rate, would imply high unemployment and inefficiently slow transition. Stabilizing nominal wage growth, in contrast, would be close to the welfare-optimal monetary policy.

**Keywords:** Structural Change, Dutch Disease, Monetary Policy.
**JEL:** E52, F41, O14.

## 1 Introduction

We study monetary policy in an open economy that is subject to a major loss in foreign exchange revenues—a so-called windfall shock. Unlike the usual assumption of temporary shocks in the monetary policy literature, we focus on the role of monetary policy under a permanent shock. At first sight, it is not at all obvious that monetary policy has a role to play when the economy faces structural change. If monetary policy is neutral in the long run, permanent shocks induce structural change completely independently of the response of the central bank. Monetary policy should deal with short-term stabilization issues, not long-term structural issues. For instance, in his Jackson Hole speech (2003), former Governor of the Reserve Bank of Australia Glenn Stevens discusses structural

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change and the conduct of monetary policy: "Changes in industries' relative shares of production or employment, [...] have always been a feature of market economies. [...] What's monetary policy's job in the face of such changes? Generally speaking, it is simply to let them occur, and to resist any temptation to use monetary policy to address the adjustment issues." This view is challenged by Guerrieri, Lorenzoni, Straub and Werning (2022), who show that monetary policy is important in mitigating welfare costs during structural reallocation.

In this paper we develop an approach to discuss how monetary policy should respond to permanent shocks which alter the steady state structure of the economy. We embed our analysis in a much studied question of such structural change among commodity exporters, namely the so-called Dutch disease; how changed resource income affects the equilibrium structure of the economy. The type of shock that we consider can be interpreted in different ways: for example, (i) Petroleum exporters are likely to face a permanent drop in export revenues when the pricing of carbon emissions becomes more widespread. (ii) Existing export markets may be captured by new countries due to shifts in technology or policy. (iii) Developing economies may have to adjust to a lower level of foreign aid when important developed countries start putting domestic issues at the top of their agendas. In short, our analysis speaks to situations where a country faces a major drop in export revenues or other sources of foreign income.

Our starting point is a situation where a permanent resource price shock implies the usual permanent (endogenous) structural transformation of the economy towards a smaller non-traded, and a larger traded, sector. Importantly, in the long run, monetary policy cannot influence overall employment or its distribution across industries. However, this does not imply that monetary policy should not respond, and there are two reasons for this. The first reason, which has been studied in numerous papers as we show below, is that (with nominal rigidities) a shock to resource prices destabilizes the economy, and monetary policy can dampen these fluctuations. The second reason, however, has to the best of our knowledge not been studied before; although monetary policy does not affect the steady state of the economy, it affects *the path and the speed of adjustment* towards the new steady state.

In this paper we show that, for monetary policy to facilitate optimal structural change, the central bank should engineer sufficient exchange rate depreciation. The reason is that, with nominal rigidities in the domestic economy, the exchange rate needs to compensate for the stickiness in non-traded prices. Without a sufficient depreciation the relative prices become misaligned, and the economy ends up in a dutch disease situation with too high unemployment and too slow transition. We analyze the welfare implications associated with different monetary policy regimes and show that common regimes, such as CPI inflation targeting or a fixed exchange rate, fail to induce sufficient real depreciation. Stabilization of nominal wage growth, in contrast, implies an appropriately expansionary policy and largely solves the problem. The reason is that wage growth targeting comes close to solving the two traditional Dutch Disease problems with one instrument: first, unemployment along the transition path is avoided. Second, a novel result from our analysis concerns the structural transition from non-traded to traded activities. In order to keep nominal wage growth constant, the central bank must initiate a lower real interest rate and a real exchange rate depreciation. It is exactly these price signals that are needed for the required structural change to gain efficient speed.

Our paper relates to a large literature on the welfare implications of alternative monetary policy strategies, see for example Aoki (2001), Woodford (2003), and Galí and Monacelli (2005), but extends this literature by considering the role of monetary policy under permanent structural change. As such, our paper is most closely related to Guerrieri, Lorenzoni, Straub and Werning (2022). They develop a two-sector model with downward nominal wage rigidies where there is a permanent shift in demand from one sector to the other. This shock generates inflation in the sector facing higher demand, but unemployment in the lagging sector. These responses imply trade-offs for monetary policy authorities in ways similar to a cost-push shock in standard one-sector models. Thus, optimal policy under such structural change involves both high inflation and unemployment. Our paper differs from Guerrieri et al. (2022) in several dimensions, the two most important being the presence of capital and that we consider an open economy. First, an essential feature of structural change is the reallocation of capital between sectors. Our model, therefore, includes investments and capital stock dynamics, both between and within sectors. Second, we want to pay particular attention to the dynamics in an open economy because the exchange rate–which jumps immediately in response to news about the future–plays an important role during the reallocation process.

As regards our particular application to structural change in commodity rich countries, our paper is related to, and merges, two independent strands of literature. The first analyzes permanent changes in resource prices and the implications for structural change, but do not consider the role of monetary policy.[1] The second literature studies monetary policy under the assumption that shocks to resource revenues only have temporary effects, thus, ignoring structural change.[2]

The rest of the paper proceeds as follows: section 2 lays out the theoretical model. Our main findings are discussed in sections 3 and 4. The former discusses the steady state, and the latter the transitional dynamics. The analytical proofs characterizing the model's steady-state properties is relegated to the appendix. Section 5 concludes.

# 2 THE MODEL

This section develops a benchmark, two-sector model of an economy with a traded and non-traded sector. The model allows us to investigate the role of policy when the economy faces a permanent fall in windfall revenues. It consists of optimizing firms in the traded and non-traded sectors, households who invest, provide labor services and consume traded and non-traded goods. Nominal frictions motivate the role for an active monetary policy. Prices and wages, in particular, are set subject to a convex adjustment cost á la Rotemberg (1982). Although the central bank is unable to affect long-run outcomes, these nominal

[1] The literature on the structural transformation from changes in natural resource income builds on Corden and Neary (1982). Contributions in this literature includes Corden (1984), van Wijnbergen (1984), Krugman (1987), Sachs and Warner (1995), Torvik (2001), Matsen and Torvik (2005), van der Ploeg and Venables (2011), Feyrer, Mansur and Sacerdote (2017), Allcott and Keniston (2018), and Bjørnland, Thorsrud and Torvik (2019). An overview of the structural transformation following shifts in natural resource incomes is given in van der Ploeg (2011).

[2] This literature includes, amongst others, Romero (2008), Catao and Chang (2013, 2015), Hevia and Nicolini (2013, 2015), Monacelli (2013), Hevia, Neumeyer and Nicolini (2013), Bergholt (2014), Ferrero and Seneca (2019), Wills (2019), and Drechsel, McLeay and Tenreyro (2019). van der Ploeg (2019) considers a permanent change in resource income, but focus on fiscal policy.

frictions do imply that monetary policy can affect the transitional path between steady states. Finally, we assume that the economy we consider is sufficiently small so that one can treat global prices and interest rates as exogenous from the point of view of the domestic economy.

## 2.1 HOUSEHOLDS

There is a unit measure of identical households. In the following, we consider a representative household which chooses consumption, bond savings, investment and capital in order to maximize expected lifetime utility $\sum_{s=t}^{\infty}\beta^{s-t}\mathbb{E}_t\mathcal{U}_s$. Following Galí (2011) we suppose that each household has a continuum of members, indexed by a pair $(i,n)$. $i\in[0,1]$ represents the type of labor service in which a given household member is specialized. $n\in[0,1]$ determines the individual worker's disutility associated with working activities. This disutility is given by $n^{\varphi}$ if the worker is employed, and zero otherwise. We denote the fraction of household members specialized in labor type $i$ by $L_{i,t}$ and assume perfect risk sharing within the household. The representative household's period utility flow $\mathcal{U}_t$ is given by

$$\mathcal{U}_t=\frac{C_t^{1-\frac{1}{\sigma}}-1}{1-\frac{1}{\sigma}}-\int_0^1\frac{L_{i,t}^{1+\varphi}}{1+\varphi}di,$$

where $C_t$ denotes aggregate consumption while $\frac{L_{i,t}^{1+\varphi}}{1+\varphi}=\int_0^{L_{i,t}}n^{\varphi}dn$ represents the aggregate disutility of work type or occupation $i$. The consumption basket consists of traded as well as non-traded consumer goods, $C_{T,t}$ and $C_{N,t}$:

$$C_t=\left(\frac{C_{N,t}}{\alpha_c}\right)^{\alpha_c}\left(\frac{C_{T,t}}{1-\alpha_c}\right)^{1-\alpha_c}$$

The associated consumer price index is $P_{c,t}=P_{N,t}^{\alpha_c}P_{T,t}^{1-\alpha_c}$. At this point we find it convenient to denote by $p_{N,t}=\frac{P_{N,t}}{P_{T,t}}$ the relative price on non-tradables. Moreover, assuming that the law of one price holds for traded goods, we define $q_t=\frac{P_{T,t}}{P_{c,t}}=p_{N,t}^{-\alpha_c}$ as the real consumer exchange rate. The household invests in real capital in the traded and non-traded sector, as well as in international capital markets. To this end we consider an aggregate investment good, $I_t$, which consists of traded and non-traded inputs, $I_{T,t}$ and $I_{N,t}$:

$$I_t=\left(\frac{I_{N,t}}{\alpha_i}\right)^{\alpha_i}\left(\frac{I_{T,t}}{1-\alpha_i}\right)^{1-\alpha_i}$$

The price index for this investment aggregate is $P_{i,t}=P_{N,t}^{\alpha_i}P_{T,t}^{1-\alpha_i}$, or $\frac{P_{i,t}}{P_{c,t}}=q_tp_{N,t}^{\alpha_i}=p_{N,t}^{\alpha_i-\alpha_c}$ in terms of consumption. Cost minimizing behavior gives rise to the following relative demand schedules at the sectoral level:

$$\frac{C_{T,t}}{C_{N,t}}=\frac{1-\alpha_c}{\alpha_c}p_{N,t}\qquad\qquad\frac{I_{T,t}}{I_{N,t}}=\frac{1-\alpha_i}{\alpha_i}p_{N,t}$$

Thus, a fixed share $\alpha_c$ ($\alpha_i$) of consumption (investment) expenditures is spent on non-traded goods each period.

The final investment good $I_t$ is distributed across sectors, $I_t = X_{N,t} + X_{T,t}$, where $X_{j,t}$ denotes the amount of gross, physical capital investments in sector $j \in \{N, T\}$. The physical capital stock $K_{j,t}$, in turn, follows a law of motion given by

$$K_{j,t+1} = (1-\delta) K_{j,t} + \left[1 - F\left(\frac{X_{j,t}}{X_{j,t-1}}\right)\right] X_{j,t},$$

where $F$ represents investment adjustment costs with the properties $F(1) = F'(1) = 0$ and $F''() \geq 0$.

Maximization is subject to an intertemporal budget constraint, expressed below in terms of consumption units:

$$C_t + q_t p_{N,t}^{\alpha_i} I_t + B_t + q_t B_t^* = \omega_t L_t + r_t^k K_t + q_t O_t + (1 + r_{t-1}) B_{t-1} + \left(1 + r_{t-1}^*\right) q_t B_{t-1}^*$$

Here, aggregate labor income is given by

$$\omega_t L_t = \int_0^1 (\omega_{i,t} L_{i,t} - \Gamma_{wi,t})\, di,$$

where $\omega_{i,t} L_{i,t} - \Gamma_{wi,t}$ represents labor income in occupation $i$, net of Rotemberg wage adjustment costs $\Gamma_{wi,t}$. These costs are specified as follows:

$$\Gamma_{wi,t} = \frac{\xi_w}{2} \left(\frac{W_{i,t}}{W_{i,t-1}} - 1\right)^2 Y_t$$

$W_{i,t}$ is the occupation-specific, nominal wage rate. In turn, gross income on physical capital is denoted by $r_t^k K_t$, where $K_t = K_{N,t} + K_{T,t}$ is the total capital stock and $r_t^k = r_{N,t}^k \frac{K_{N,t}}{K_t} + r_{T,t}^k \frac{K_{T,t}}{K_t}$ is the associated rental rate (with sectoral rates $r_{j,t}^k$ appropriately weighted). $O_t$ is the exogenously given resource windfall, which in the continuation we simply term oil. Finally, $B_t$ and $B_t^*$ represents domestic and foreign bond holdings which pay interests $r_t$ and $r_t^*$ the following period. The dynamics of $r_t^*$ are specified further below.

Optimality conditions with respect to consumption, domestic and foreign bond holdings, capital and investments in each sector, respectively, follow:

$$C_t^{-\frac{1}{\sigma}} = \Lambda_t \tag{1}$$

$$\Lambda_t = \beta \mathbb{E}_t \Lambda_{t+1} (1 + r_t) \tag{2}$$

$$\Lambda_t = \beta \mathbb{E}_t \Lambda_{t+1} (1 + r_t^*) \frac{q_{t+1}}{q_t} \tag{3}$$

$$\Lambda_t \mathcal{Q}_{j,t} = \beta \mathbb{E}_t \Lambda_{t+1} \left[r_{j,t+1}^k + (1-\delta) \mathcal{Q}_{j,t+1}\right] \tag{4}$$

$$\Lambda_t p_{N,t}^{\alpha_i - \alpha_c} = \Lambda_t \mathcal{Q}_{j,t} \left(1 - F_t - F_t' \frac{X_{j,t}}{X_{j,t-1}}\right) + \beta \mathbb{E}_t \Lambda_{t+1} \mathcal{Q}_{j,t+1} F_{t+1}' \left(\frac{X_{j,t+1}}{X_{j,t}}\right)^2 \tag{5}$$

Here, $\Lambda_t$ represents the Lagrangian multiplier associated with the budget constraint, while $\mathcal{Q}_t$ is the multiplier associated with the law of motion for capital. To ease the notational burden we have defined $F_t \equiv F\left(\frac{X_t}{X_{t-1}}\right)$ and $F_t' \equiv F'\left(\frac{X_t}{X_{t-1}}\right) \equiv \frac{\partial F\left(\frac{X_t}{X_{t-1}}\right)}{\partial X_t}$, respectively. Equation (1) states that the marginal utility gain of consumption is equal to $\Lambda_t$, the shadow value of a marginal increase in income. Equation (2) is the consumption Euler equation which determines the optimal savings plan with respect to domestic bonds, equation (3) is the counterpart for savings in foreign bonds. Equation (4) defines the present value of installed capital, denoted by $\mathcal{Q}_t$. Equation (5) states that one should invest in capital until the marginal return of those investments are equal to the marginal utility gain of consumption.

## 2.2 LABOR MARKET DYNAMICS

Following along the lines of Galí (2011), we suppose that workers supplying labor of a given type $i$ set a wage rate $W_{i,t}$ in order to maximize household utility. In contrast to Galí, we assume nominal wage stickiness á la Rotemberg (1982) (rather than Calvo (1983)) and arrive at a New Keynesian wage Phillips curve of the following form:

$$\begin{aligned}(\epsilon_w - 1)(1+\tau_w) = \epsilon_w \frac{C_t L_t^{\varphi}}{\omega_t} - \xi_w (\Pi_{w,t} - 1)\Pi_{w,t}\frac{Y_t}{\omega_t L_t} \\ + \beta \mathbb{E}_t \frac{\Lambda_{t+1}}{\Lambda_t}\xi_w (\Pi_{w,t+1} - 1)\Pi_{w,t+1}\frac{Y_{t+1}}{\omega_t L_t} \qquad (6)\end{aligned}$$

This equation implies that wage inflation $\Pi_{w,t}$ responds positively to current and expected future gaps between the marginal rate of substitution between consumption and leisure, given by $C_t L_t^{\varphi}$, and the real wage $\omega_t$. Note that we have included a wage subsidy of size $\tau_w$, which, when calibrated appropriately, makes labor supply efficient in steady state (as is standard in the literature). The individual worker $n$, in contrast, takes the prevailing wage as given and prefers to be employed as long as $\omega_{i,t} \geq C_t n_t^{\varphi}$. Aggregate labor supply follows as

$$\omega_t = C_t N_t^{\varphi}, \qquad (7)$$

where $\omega_t = \int_0^1 \omega_{i,t} di$ is the aggregate wage and $N_t = \int_0^1 n dn$ is interpreted as the aggregate participation rate (which is the same in all occupations due to the symmetry associated with the Rotemberg adjustment cost). Accordingly, we define the unemployment rate $U_t$ as share of unemployed workers:

$$U_t = 1 - \frac{L_t}{N_t} \qquad (8)$$

Comparing equations (6) and (7), it follows that $U = 1 - \left(\frac{\epsilon_w - 1}{\epsilon_w}(1+\tau_w)\right)^{\frac{1}{\varphi}}$ at all times in absence of nominal wage rigidities ($\xi_w = 0$). Finally, aggregate labor is distributed freely across sectors, so that $L_t = L_{N,t} + L_{T,t}$.

## 2.3 FIRMS

Firms in the domestic economy operate either in the traded sector or the non-traded sector. Output of a representative firm in each sector $j \in [N, T]$ is given by a Cobb-Douglas production function with constant returns to scale:

$$Y_{j,t} = A_{j,t} L_{j,t}^{\mu_j} K_{j,t}^{1-\mu_j} \qquad (9)$$

While firms in the traded sector sell their output in competitive markets and take the market price as given, non-traded firms face monopolistic competition and set individual prices subject to a Rotemberg (1982) adjustment cost:

$$\Gamma_{pf,t} = \frac{\xi_p}{2}\left(\frac{P_{Nf,t}}{P_{Nf,t-1}} - 1\right)^2 Y_{N,t}$$

$P_{Nf,t}$ is the price set by firm $f \in [0,1]$.

The environment we consider gives rise to a set of standard optimality conditions which determine the demand by firms in each sector for labor and capital services:

$$\omega_t = \mu_T p_{N,t}^{-\alpha_c}\frac{Y_{T,t}}{L_{T,t}} \qquad \omega_t = \mu_N p_{N,t}^{1-\alpha_c} MC_{N,t}\frac{Y_{N,t}}{L_{N,t}} \tag{10}$$

$$r_{T,t}^k = (1-\mu_j)\, p_{N,t}^{-\alpha_c}\frac{Y_{T,t}}{K_{T,t}} \qquad r_{N,t}^k = (1-\mu_j)\, p_{N,t}^{1-\alpha_c} MC_{N,t}\frac{Y_{N,t}}{K_{N,t}} \tag{11}$$

Note that the demand for factor inputs among non-traded firms is distorted by fluctuations in their real marginal costs $MC_{N,t}$. This feature comes about from price stickiness in the non-traded sector. Moreover, price stickiness in the non-traded sector implies that, in a symmetric equilibrium, non-traded inflation $\Pi_{N,t}$ depends on current and expected future non-traded real marginal costs:

$$\begin{aligned}(\epsilon_p - 1)(1+\tau_p) = \epsilon_p MC_{N,t} - \xi_p(\Pi_{N,t}-1)\Pi_{N,t} \\ + \beta\mathbb{E}_t\frac{\Lambda_{t+1}}{\Lambda_t}\xi_p(\Pi_{N,t+1}-1)\Pi_{N,t+1}\frac{Y_{t+1}}{Y_t}\end{aligned} \tag{12}$$

As for the labor market we have included the possibility of a price subsidy of size $\tau_p$ which, when calibrated appropriately, can make the non-traded goods market efficient in steady state. It follows that $MC_N = \frac{\epsilon_p - 1}{\epsilon_p}(1+\tau_p)$ at all times in absence of nominal price rigidities in the non-traded sector ($\xi_p = 0$), implying a constant real marginal cost. The marginal costs, in turn, are determined by the factor prices faced by non-traded firms:

$$MC_{N,t} = \frac{1}{A_{N,t}}\left(\frac{\omega_t}{\mu_N}\right)^{\mu_N}\left(\frac{r_{N,t}^k}{1-\mu_N}\right)^{1-\mu_N} \tag{13}$$

This concludes the description of firm behavior in the domestic economy.

### 2.4 Oil, trade, and current account dynamics

The model is closed with a description of the home economy's current account dynamics. To this end we note that the external trade balance is given by:

$$NX_t = Y_{T,t} + O_t - C_{T,t} - I_{T,t} \tag{14}$$

The net foreign asset position of the home economy follows:

$$q_t B_t^* = (1 + r_{t-1}^*) q_t B_{t-1}^* + NX_t \tag{15}$$

In order to close the model, we assume that the foreign real interest rate remains fixed, but include a sovereign risk premium á la Schmitt-Grohe and Uribe (2003). The premium is decreasing in the net foreign asset position of the domestic economy, and prevents temporary monetary policy actions from having permanent effects. The effective real interest rate on foreign bonds follows:

$$1 + r^*_{t-1} = (1 + r^*)\,\mathcal{R}_{t-1} \qquad\qquad \mathcal{R}_t = \exp\left(\frac{-\chi(B^*_t - B^*)}{GDP}\right)$$

Importantly, the premium affects the exchange rate via the UIP condition. By combining the optimality conditions with respect to foreign and domestic bond holdings, we arrive at a UIP condition of the form

$$\mathbb{E}_t\left\{\beta\frac{\Lambda_{t+1}}{\Lambda_t}\left[(1 + r_t) - (1 + r^*)\,\frac{q_{t+1}}{q_t}\mathcal{R}_t\right]\right\} = 0. \tag{16}$$

Finally, we can re-write the intertemporal budget constraint in order to express the domestic economy's gross domestic product:

$$GDP_t = C_t + I_t + NX_t \tag{17}$$

Implicitly in our model is the assumption that fiscal policy is fully Ricardian, with public debt, taxes and subsidies being financed by lump-sum transfers. This concludes our description of the model.

# 3 The new steady state with lower oil income

A permanent oil price fall has both short run and long run effects, as it also changes the steady state. The new steady state with a permanently lower level of oil income is independent of monetary policy. Nevertheless, it has a number of important, structural characteristics which are key to understand the transitional dynamics to which we turn to below. In the appendix we provide the analytical proofs characterizing the new steady state. In the following, we explain the intuition behind these results.

First, there is no change in relative prices. This is a well known result, which follows from our assumption of constant return to scale production functions. When this is the case, then relative prices are fully determined by supply-side factors, regardless of the level of demand.

Second, the fall in oil income, which implies a permanent decline in income, gives rise to a decline in aggregate consumption, as well as an increase in aggregate labor supply. This follows from our assumption that both consumption and leisure are normal goods. Since consumption is lower and all relative prices, including the real wage, are unchanged, there is no substitution effect in labor supply. There is thus only an income effect, which implies that labor supply increases.

Third, the decline in oil revenues implies a higher aggregate capital stock (and hence, a higher level of aggregate investments) in the new steady state. With constant returns to scale combined with unchanged factor prices, the optimal capital stock is proportional to labor supply, which increases. In our framework, however, there is an additional force further stimulating capital accumulation: the decline in consumption implies a structural transformation towards the relatively capital intensive traded sector. This cross-sectional reallocation further increases the capital stock so that the overall capital intensity also increases.

Fourth, production in the traded sector increases, both in absolute terms and relative to the production level in the non-traded sector. There are three forces pulling tradable output up: first, in the new steady state, oil income can finance less traded goods imports. To compensate for this, labor must reallocate from non-traded to traded production activities. Second, tradable output increases because of the rise in aggregate labor supply. Third, traded output is stimulated by the structural transformation towards a higher capital intensity in the aggregate economy. Importantly, while the second mechanism also stimulates non-traded output, the first and last effects pull non-traded output down. This explains why the traded sector must increase also relative to the non-traded sector.

# 4 TRANSITIONAL DYNAMICS

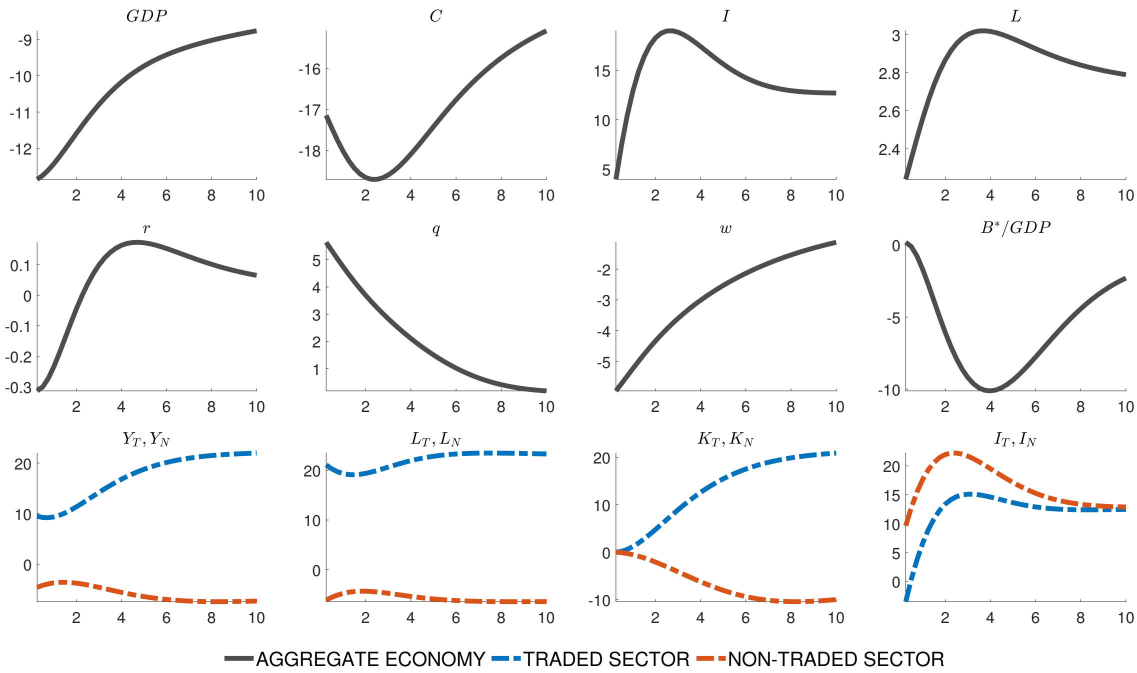
We now turn to the main contribution of our paper, which is the role of monetary policy in the transitional dynamics towards the new steady state. It is instructive to first analyze the transition path which would appear if prices and wages were fully flexible. As long as the subsidies $\tau_w$ and $\tau_p$ are set appropriately (see below), this transition path is efficient from a welfare point of view. Thus, these transitional dynamics serve as a useful benchmark when we later compare alternative monetary policy regimes.

Table 1: Calibration

| | *Parameter* | *Value* |
|---|---|---|
| $\beta$ | Discount factor | 0.99 |
| $\sigma$ | Intertemporal elasticity of substitution | 1 |
| $\varphi$ | Inverse Frisch elasticity of labor supply | 5 |
| $\delta$ | Capital depreciation | 0.025 |
| $\alpha_c$ | Non-traded share consumption | 0.43 |
| $\alpha_i$ | Non-traded share investment | 0.57 |
| $\mu_T$ | Labor share traded | 0.45 |
| $\mu_N$ | Labor share non-traded | 0.75 |
| $\epsilon_w$ | Elasticity of substitution, labor types | 6 |
| $\epsilon_p$ | Elasticity of substitution, non-traded goods | 6 |
| $\xi_w$ | Wage adjustment | 655 |
| $\xi_p$ | Price adjustment | 26 |
| $F''$ | Investment adjustment cost | 4 |
| $\chi$ | Risk premium elasticity | 0.01 |

*Note:* This calibration targets a number of empirical moments in the Norwegian economy over the sample period 1970-2020. In particular, we target the sample averages of non-traded share in consumption of 0.43, non-traded share in investment of 0.57, an aggregate investment share in GDP of 0.21, a traded share in GDP of 0.27, and finally a petroleum share in GDP of 0.25.

Figure 1: Transitional dynamics in absence of nominal rigidities




We calibrate the model and solve it assuming perfect foresight.[3] The calibration is fairly standard and given in Table 1. Importantly, we consider a calibration which is consistent with a defining sectoral characteristic of most small, open economies: the traded sector is significantly more capital intensive than the non-traded sector. Turning to the nominal frictions, our calibration of the Rotemberg adjustment costs is such that, when mapped into the Calvo model, wages and prices would change on average every third quarter (i.e. a Calvo parameter of $0.65$). Up to a first order approximation, this calibration also implies that the elasticity of non-traded inflation with respect to non-traded output is about the same as the elasticity of wage inflation with respect to unemployment. The wage subsidy $\tau_w$ is set equal to $\frac{1}{\epsilon_w - 1}$, and the price subsidy $\tau_p$ equal to $\frac{1}{\epsilon_p - 1}$. Our calibration of the wage subsidy removes the steady state distortion in labor markets and implies that unemployment is zero in steady state. Our calibration of the price subsidy removes the steady state distortion in goods markets and implies that the real marginal cost is unity in steady state. Combined, these subsidies guarantee that the steady state of our model is efficient. Moreover, they imply that in absence of price and wage rigidities, also the transitional dynamics are efficient. This flexible price and wage economy thus serves as a useful benchmark for the policy regimes we consider later.

### 4.1 Flexible prices and wages

We start with a normatively interesting case, namely what the transition would look like if prices and wages were fully flexible ($\xi_w = \xi_p = 0$). With our assumptions, this is the welfare optimal transition. Then, we re-introduce sticky prices and wages and analyze what the transition would look like under alternative monetary policy regimes, including

[3] Standard Newton methods are used to solve the system of non-linear equations.

how the alternative regimes perform in terms of welfare. Throughout the analysis we consider a *permanent* oil price decline which reduces oil revenues by $50\%$.

The transitional dynamics under full price and wage flexibility are shown in Figure 1. Each subplot shows the percentage response in the variable(s) of interest along the vertical axis, and time measured in years on the horizontal axis. Impulse responses in black represent dynamics in the aggregate economy, while impulse responses in blue (red) represent the traded (non-traded) sector.

In the short run, the capital stock in each sector is given. This, combined with the fall in demand for non-traded goods, makes the value of expected marginal product of capital in the non-traded sector decline. A lower marginal product of capital has two important implications: first, the real wage drops. Second, the domestic real interest rate declines, causing the real exchange rate to depreciate. Combined, these price effects provide the incentives needed to bring the economy on an optimal path towards the desired structural change. Importantly, the decline in the real interest rate stimulates demand for goods in both sectors in the domestic economy. The real exchange rate depreciation, in contrast, stimulates a reallocation of resources from non-traded sector to traded sector activities.

The initial jump in the real exchange rate is gradually reversed over time, as the sector specific capital stocks converge towards their new long run levels. As capital reallocation moves forward, the real interest rate gradually increases. However, the real interest rate path in our framework is also affected by another mechanism: the sudden fall in oil income implies a current account deficit. Moreover, as investments gradually increase, the current account balance is further weakened. These net foreign asset dynamics translate into a rise in the sovereign risk premium, and thus push the real interest rate further up. The temporarily low levels of the real interest rates dampen the short run fall in consumption. Thus, after the initial fall, consumption continues to decline. Note that, due to the risk premium effect on the interest rate, consumption temporarily undershoots its new steady state level.

We next introduce nominal wage and price stickiness, and revisit the transitional dynamics under alternative monetary policy regimes.

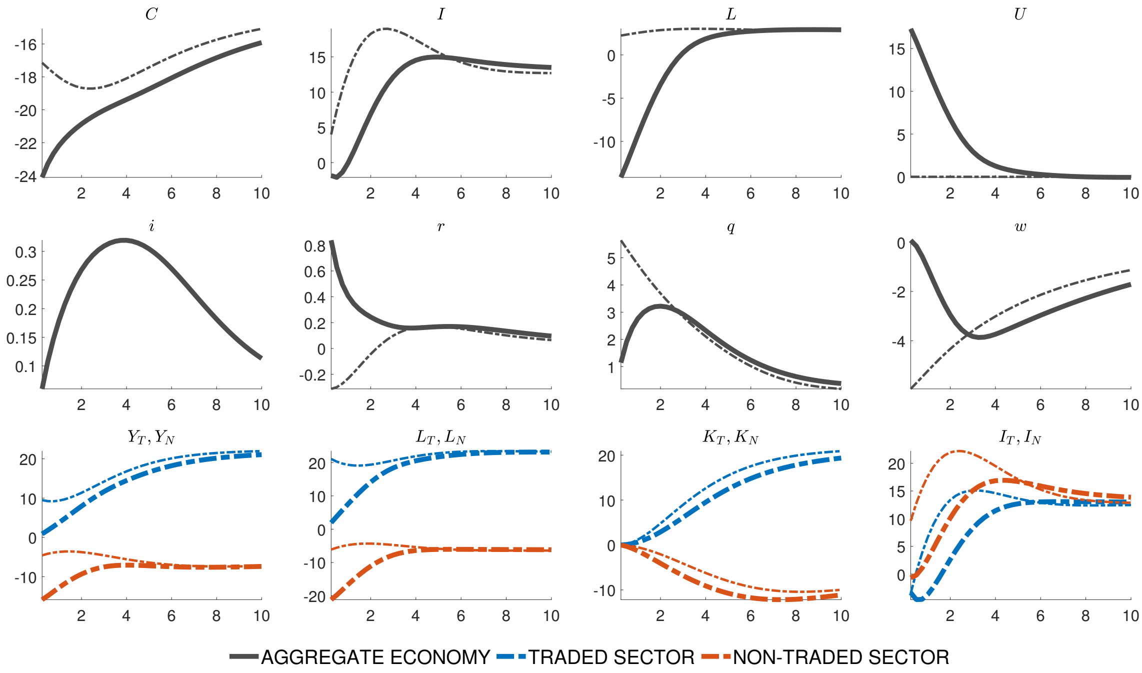
## 4.2 STICKY WAGES AND PRICES

In order to illustrate the role of monetary policy during structural change, we consider the following *strict* targeting regimes:

1. A fixed exchange rate (monetary union): $\Pi_{T,t} = 0$
2. CPI inflation targeting: $\Pi_{c,t} = 0$
3. Non-traded inflation targeting: $\Pi_{N,t} = 0$
4. Wage growth targeting: $\Pi_{w,t} = 0$

By strict targeting, we refer to policies that consider only one stabilization target (e.g. the exchange rate) at the time. One may think of such policies as special cases of instrument rules, where the coefficient on the target variable takes a very high value. In this way, we focus on the defining differences between the alternative regimes. In practice, central banks do not conduct strict versions of inflation targeting, but rather put some weight on

Figure 2: Transitional dynamics with an exchange rate peg




*Note:* Impulse responses under a fixed exchange rate regime (or monetary union) are given by thick lines. The optimal paths are given by thin lines.

stability in the real economy as well. Taking this into account will not alter our results qualitatively, but reduces the quantitative welfare differences between the policies we consider.

The policy problem is to design a monetary policy regime that comes as close as possible to the flex-price solution when measured by households' welfare. In order to compare different policies, we let $i$ denote a specific monetary policy regime. Thus, lifetime welfare in regime $i$ in period $t$ can be expressed as:

$$\mathcal{W}_{i,t} = \sum_{s=t}^{\infty} \beta^{s-t} \left( \frac{C_{i,s}^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}} - \Psi \frac{L_{i,s}^{1+\varphi}}{1+\varphi} \right)$$

We compare lifetime welfare given sticky prices and wages (and a specified monetary policy regime) with the counterfactual case with full price and wage flexibility. Denote lifetime welfare under full wage and price flexibility by $\mathcal{W}_{f,t}$. In order to quantify welfare costs, we compute the necessary increase in consumption in the case with price/wage stickiness, denoted by $\lambda_i$, such that household welfare would be the same as under the counterfactual case with full price and wage flexibility:

$$\sum_{s=t}^{\infty} \beta^{s-t} \left( \frac{((1+\lambda_i)C_{i,s})^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}} - \Psi \frac{L_{i,s}^{1+\varphi}}{1+\varphi} \right) = \sum_{s=t}^{\infty} \beta^{s-t} \left( \frac{C_{f,s}^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}} - \Psi \frac{L_{f,s}^{1+\varphi}}{1+\varphi} \right)$$

It follows that

$$\lambda_i = \left(1 + \frac{\mathcal{W}_{f,t} - \mathcal{W}_{i,t}}{\mathcal{W}^c_{i,t}}\right)^{\frac{\sigma}{\sigma-1}} - 1, \qquad \text{where} \qquad \mathcal{W}^c_{i,t} = \sum_{s=t}^{\infty} \beta^{s-t} \frac{C_{i,s}^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}}.$$

The monetary policy regime $i$ that implies the lowest transfer $\lambda_i$ is, by construction, the better monetary policy regime.

#### 4.2.1 FIXED EXCHANGE RATE

The transition process under a fixed exchange rate regime (or monetary union) is shown in Figure 2 as the thick lines. For comparison we also plot the dynamics when prices and wages are flexible as thin lines. The figure illustrates two fundamental problems associated with the transition path that follows from a fixed exchange rate regime. First, recall that the optimal transition path involves an immediate real exchange rate depreciation. But when nominal wages and (non-traded) prices are sticky, this can only happen via a depreciation of the nominal exchange rate. However, since the defining characteristic of this regime is a fixed nominal exchange rate, this cannot happen. Second, the optimal transition path also involves a decline in the real interest rate. However, in order to neutralize the depreciation due to a higher risk premium, the central bank must instead pursue a policy which leads to a rise both in the nominal and real interest rate. In total, therefore, the fixed exchange rate regime achieves price signals that differ fundamentally from those associated with the optimal transition path.

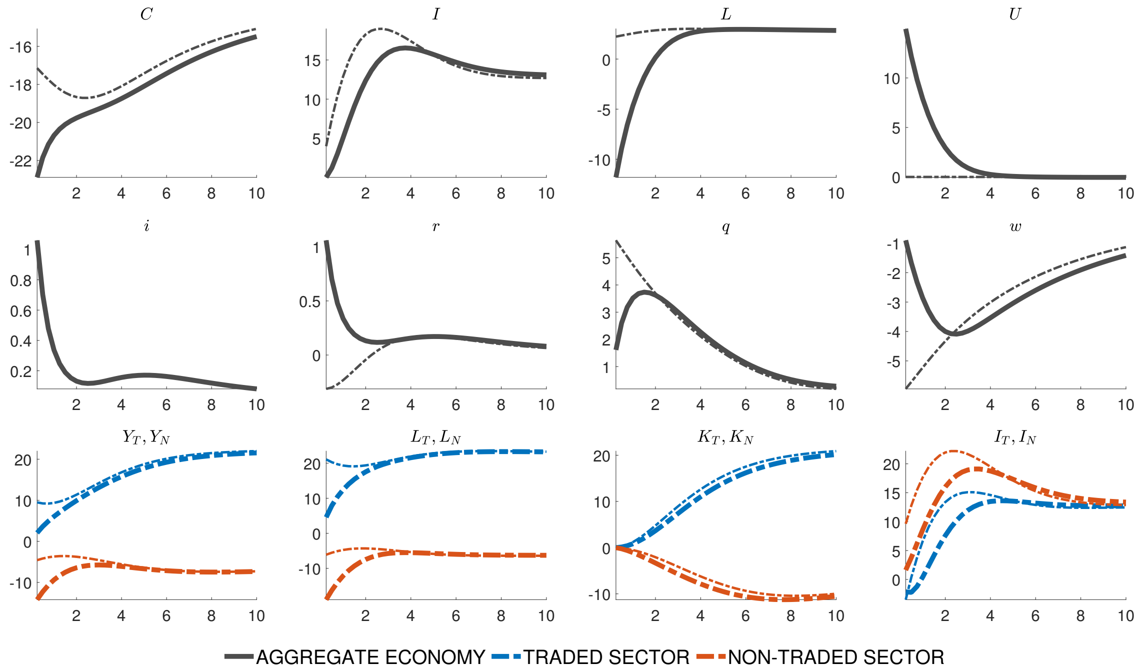
As seen from Figure 2, the interest rate hike exacerbates the fall in aggregate demand, and the result is a sharp increase in unemployment. Moreover, keeping the exchange rate fixed prevents the structural adjustments needed to increase the size of the traded sector. Investments in traded sector capital are delayed and do not increase significantly until the real wage level has eventually come down as a result of the slack labor market. The workers laid off in the non-traded sector are not absorbed by the traded sector due to the lack of real exchange rate depreciation. As seen from the figure, capital stocks and labor use in the traded sector are too low for too long. These are classical symptoms of the Dutch Disease. However, in contrast to much of the previous literature, which has focused on excessive public spending in response to oil income, in our setting it is the combination of rigidities and sub-optimal monetary policy that infects the economy with the disease.

Table 2 reports the implied welfare loss. Given our calibration, the fixed exchange rate regime implies a relatively large welfare loss, with $\lambda = 0.65$. Put differently, permanent consumption must rise by more than $0.6\%$ for the representative household to be indifferent between the fixed exchange rate regime and the optimal transition path.

#### 4.2.2 CPI INFLATION TARGETING

Inflation targeting is by far the most popular monetary policy regime in the world. Basically all of the inflation targeting central banks have the CPI as their target variable. While the CPI is generally not an optimal price target index from a strict welfare theoretical perspective, there are other reasons for specifying the inflation target in terms of the CPI, for example that the CPI is well established and well understood among the public.

Figure 3: Transitional dynamics with CPI targeting




*Note:* Impulse responses under a fixed exchange rate regime (or monetary union) are given by thick lines. The optimal paths are given by thin lines.

Table 2: Welfare comparison of alternative regimes

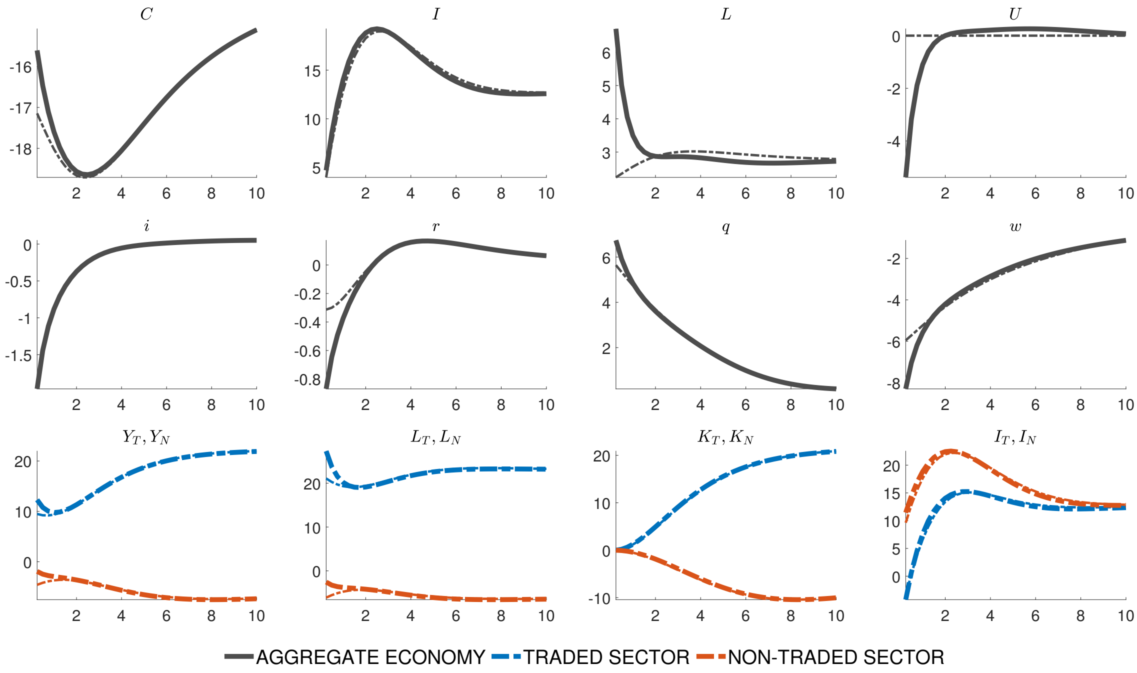
| | *Regime* | | | |
|---|---|---|---|---|
| | $\Pi_{T,t} = 0$ | $\Pi_{c,t} = 0$ | $\Pi_{N,t} = 0$ | $\Pi_{w,t} = 0$ |
| $\lambda$ | 0.6457 | 0.3029 | 0.0957 | 0.0004 |

*Note:* Percentage increase in permanent consumption (per period) that makes the household indifferent between outcomes.

The CPI has, however, a considerable component of imported goods, and the exchange rate is therefore important for the CPI development.

Figure 3 shows the transition process under CPI inflation targeting. Since the oil price shock gives rise to an exchange rate depreciation, which increases traded sector inflation, the central bank must raise the interest rate to prevent overall CPI inflation from increasing above the target. Constant CPI inflation requires a small depreciation, but where the effect of somewhat higher traded sector inflation on CPI inflation is offset by a small decrease in non-traded inflation. The latter is a result of lower demand for non-traded goods. The contractionary monetary policy response reduces investments and counteracts, at least in the short run, the structural adjustment towards a larger traded sector relative to the non-traded sector. The rise in the short term real interest rate is considerably larger than in the fixed exchange rate regime, but the real interest rate comes down faster than with a fixed exchange rate. The latter effect dominates, implying that consumption and

Figure 4: Transitional dynamics with non-traded inflation targeting




*Note:* Impulse responses under a fixed exchange rate regime (or monetary union) are given by thick lines. The optimal paths are given by thin lines.

investments fall less under CPI targeting. The intuition for a more temporary interest rate hike under CPI targeting is that some of the relative price changes are allowed to occur via the nominal exchange rate, which is flexible. Under an exchange rate peg, in contrast, all relative price changes must be accomplished via wages and non-traded prices, which are sticky. The necessary price and structural adjustments, therefore, occurs faster with CPI targeting.

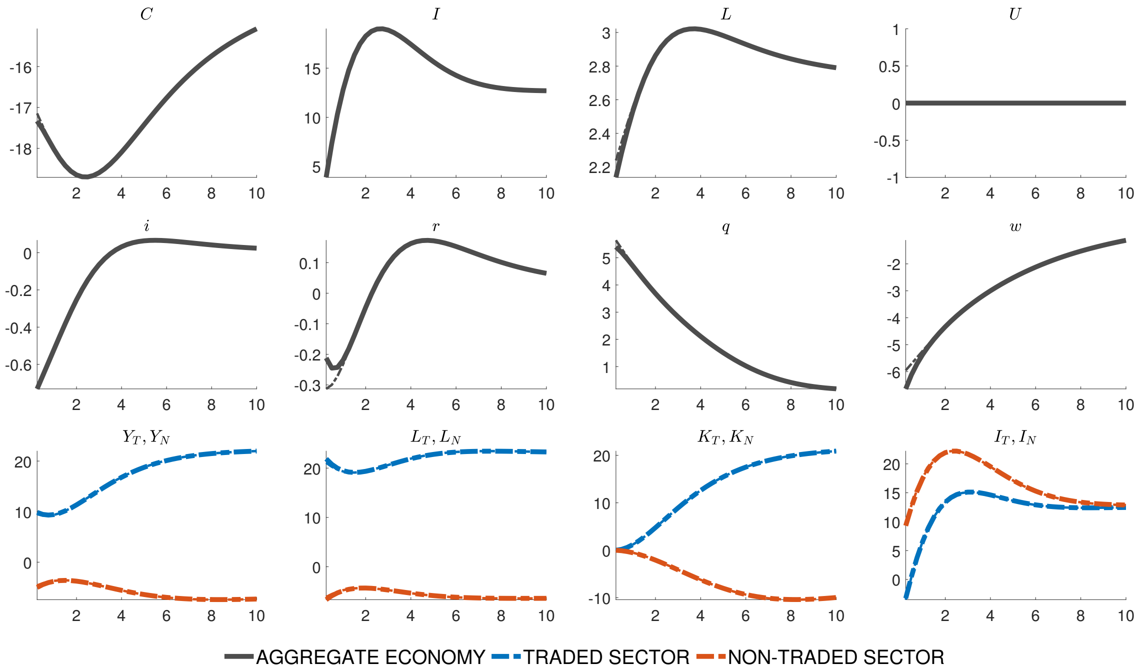
As a consequence of the above, the increase in unemployment becomes larger, but less long-lasting, under CPI inflation targeting than with a fixed exchange rate. The second column in Table 2 reports the value of $\lambda$, showing that the welfare loss under CPI targeting, even if it is high, is less than half compared to the fixed exchange rate regime.

#### 4.2.3 Non-traded inflation targeting

In some open-economy models, such as Galí and Monacelli (2005), it is optimal for the central bank to stabilize domestic inflation. This hinges on the assumption of perfect pass-through from foreign prices and the exchange rate to import prices. This is also the case in our model, but in addition to sticky non-traded prices, we have sticky wages. Stabilizing only non-traded inflation is therefore not optimal in our model. Non-traded inflation targeting is still an interesting regime to analyze, for example to investigate whether the absence of a direct exchange rate channel to inflation makes monetary policy respond more appropriately to the oil price fall.

As seen from Figure 4, the suboptimal increase in the interest rate that we found under

Figure 5: Transitional dynamics with nominal wage growth targeting




*Note:* Impulse responses under a fixed exchange rate regime (or monetary union) are given by thick lines. The optimal paths are given by thin lines.

CPI inflation targeting is avoided. Indeed, the interest rate must be reduced in order to prevent non-traded goods prices from falling as a response to lower demand. In fact, the nominal interest rate decline required to keep non-traded demand and inflation up is substantial, and it leads to a real interest rate decline which is even larger than in the economy with flexible prices and wages. In order to understand the excessive interest rate decline under non-traded inflation targeting, note that, in the flex price/wage solution, non-traded output falls. Thus, when the central bank targets non-traded inflation directly, it must engineer an even larger decline in the real interest in order to prevent non-traded output, and thereby non-traded inflation, from falling.

Observe that non-traded inflation targeting leads to a rise in employment. At the same time, labor supply decreases relative to optimal response. This is due to relatively low real wages. Since we have defined unemployment as the difference between desired and actual levels of employment, this explains why unemployment becomes negative.

While CPI inflation targeting results in too slow structural adjustments towards the new steady state, the opposite is true for non-traded inflation targeting. The level of investments is too high in the first years after the shock, which means that there is thus less need for investments in later stages of the adjustment process. The unemployment gap therefore goes from negative in the first years, but eventually becomes positive due to lower investments. The welfare loss is, as shown in Table 2, still considerably lower than its counterpart under CPI inflation targeting.

#### 4.2.4 WAGE GROWTH TARGETING

Replacing a traditional inflation target by a wage growth target has been suggested by Erceg, Henderson and Levin (2000) and Mankiw and Reis (2003). However, wage growth targeting has not been a serious contender to inflation targeting in the monetary policy debate, although it spurred some interest after Olivier Blanchard at the Brookings conference in 2019 suggested that the Fed should consider targeting nominal wage growth.[4] While the welfare-theoretical rationale for wage growth targeting is sound, as wages tend to be more sticky than prices, using monetary policy to control wage growth is controversial. It may be seen as interfering with wage negotiations, especially in countries with coordinated wage bargaining. Against this argument, one can argue that wage growth targeting is not that different from inflation targeting, since an inflation targeting central bank has to respond to wage growth due to the close relation between wages and prices.

The transition dynamics under wage growth targeting is illustrated in Figure 5. As seen from the figure, keeping nominal wage growth constant leads to almost the same outcome as in the case with fully flexible wages and prices. Table 2 confirms that the welfare loss under wage growth targeting is only marginally higher than the flex-price welfare loss. At first glance, this results may seem surprising, since the existence of two imperfections—sticky wages and sticky non-traded prices—gives a trade-off in monetary policy, so that welfare optimum cannot in general be achieved by stabilizing only one of them. Still, stabilizing wages comes very close to welfare optimum. The reason is that wage growth targeting comes close to solving the two traditional Dutch Disease problems with one instrument: first, unemployment along the transition path is avoided. This is similar to Galí (2011), who shows that the New Keynesian model with sticky wages implies a simple dynamic relation between wage growth and unemployment. In such a framework, one can prevent all unemployment fluctuations by strictly targeting wage inflation. Second, a novel result from our analysis concerns the structural transition from non-traded to traded activities. The reason is that, in order to keep nominal wage growth constant, the central bank must initiate a lower real interest rate and a real exchange rate depreciation. It is exactly these price signals that are needed for the required structural change to take place.

## 5 ROBUSTNESS ANALYSIS

Next, we set out to analyze how robust our main results are when we change various assumptions embedded in the baseline model. The exercises we consider are described below, with associated welfare losses (expressed by $\lambda$) summarized in Table 3.

- First, we follow Mendoza (1991) and set the risk premium elasticity to $\chi = 2$, as opposed to $\chi = 0.01$ in the baseline. This calibration implies a substantial rise in the risk premium when the overall trade balance deteriorates, compared with our baseline scenario.

- The role of nominal rigidities: we first set $\xi_w = 0$, implying full wage flexibility. Then we set $\xi_p = 0$, implying full non-traded price flexibility.

[4]Speech at the Brookings Institution, October 3 2019, available at https://www.brookings.edu.

Table 3: Robustness tests: welfare losses ($\lambda$)

| | *Regime* | | | |
|---|---|---|---|---|
| | $\Pi_{T,t}=0$ | $\Pi_{c,t}=0$ | $\Pi_{N,t}=0$ | $\Pi_{w,t}=0$ |
| Baseline model | 0.6457 | 0.3029 | 0.0957 | 0.0004 |
| *Alternative specifications* | | | | |
| High risk premium elasticity | 0.7334 | 0.3508 | 0.0974 | 0.0005 |
| Full wage flexibility | 0.0350 | 0.0164 | 0.0000 | 0.0004 |
| Full non-traded price flexibility | 0.6011 | 0.2529 | 0.0957 | 0.0000 |
| Low intertemporal elasticity of substitution | 1.2729 | 0.6494 | 0.0462 | 0.0003 |
| High Frisch elasticity | 0.6351 | 0.3175 | 0.0069 | 0.0002 |
| Low investment adjustment costs | 0.5624 | 0.2807 | 0.0557 | 0.0003 |
| High non-traded share in consumption | 1.6502 | 0.5555 | 0.0605 | 0.0006 |
| High non-traded share in investments | 0.9078 | 0.4480 | 0.0305 | 0.0002 |
| Only labor in non-traded output | 1.2204 | 0.6958 | 0.0009 | 0.0000 |

- We consider more curvature in the preferences for consumption by setting the IES to $\sigma = 0.5$, as opposed to $\sigma = 1$ (log utility). This calibration strengthens households' desire for a smooth consumption path.

- We raise the Frisch elasticity $\varphi^{-1}$ by setting $\varphi = 1$, as opposed to $\varphi = 5$. This alternative calibration of $\varphi$ implies a very high income effect of wage changes on labor supply, considerably higher than the values typically found in empirical, microeconometric work.

- We assume that investments can be almost freely adjusted by calibrating investment adjustment costs so that $F''(1) = 1$, as opposed to $F''(1) = 4$.

- We explore the role of home bias in consumption by setting $\alpha_c = 0.6$, as opposed to $\alpha_c = 0.43$.

- Next, we assume a high home bias in investments and set $\alpha_i = 0.9$, as opposed to $\alpha_i = 0.57$.

- Finally, we set $\mu_N = 1$ as opposed to $\mu_N = 0.75$ in order to rank policies in a situation where only labor is used as input in the non-tradable sector.

In all but one of these robustness exercises, the welfare rankings of our alternative monetary policy regimes remain unchanged. The only exception we identify is when wages are fully flexible. In this case, strict targeting of non-traded inflation removes all welfare losses. This is as expected, since non-traded price stickiness is the only nominal distortion left when wages are fully flexible. Similarly, a strict wage target removes all welfare losses if non-traded prices are fully flexible.

# 6 Conclusion

In this paper, we have developed a model tailored to study the role of monetary policy under structural transition. Unlike the conventional approach, we have focused on a situation where shocks alter the steady state of the economy, and where the design of monetary policy affects the transition path, and its speed, towards the new long-run equilibrium structure of the economy. For a resource exporting economy, a permanent drop in resource prices implies that in the long run, factors of production must shift out of non-traded and into traded sector activities. Even if monetary policy is neutral in the long run, it does affect exactly how, and how fast, the economy approaches its new long-run equilibrium. Because of this, the design of monetary policy has important welfare implications.

In our setting, the transition path that would appear in absence of nominal rigidities would be welfare optimal. The transition path is characterized by a significant real exchange rate depreciation, combined with a downward shift in the real interest rate. These price signals combat the two main symptoms of a Dutch disease, namely transitional unemployment and too slow capital reallocation from the non-traded to the traded sector.

The presence of nominal price and wage rigidities distorts this picture, and thereby provides a rationale for our study of different monetary policy regimes. Our main findings are as follows: a regime which keeps the nominal exchange rate fixed prevents the desired real exchange rate depreciation in the short run. In turn, this leads to a substantial rise in unemployment and limited capital reallocation for a prolonged period of time. CPI inflation targeting does not eliminate these problems as long as there is exchange rate pass-through into prices. This is because the central bank must raise the policy rate in order to combat imported price growth under an inflation targeting regime. At the same time we find that targeting non-traded inflation, which in contrast to CPI inflation is not directly affected by the exchange rate, implies a monetary policy response that is too expansionary. In particular, such a monetary policy stance implies excessive exchange rate depreciation. Nominal wage growth targeting turns out be the Goldilocks regime—it puts the economy on a transition path that is neither too slow, nor too fast.

It follows that monetary policy can be an efficient tool in curing the Dutch disease. Note that a traditional fiscal policy response, which leads to increased aggregate demand, can also solve the unemployment problem. But this comes at the expense of a slower structural change, since such a policy typically implies a real exchange rate appreciation. An appropriate monetary policy stance, on the other hand, prevents unemployment at the same time as it achieves exchange rate depreciation. The latter price signal is a necessary ingredient in order to initiate structural change.

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# APPENDIX

## A ANALYTICAL CHARACTERIZATION OF THE STEADY STATE

In this appendix, we characterize the steady state of the model, and prove analytically the properties laid out in the main text. To this end we set $\tau_w$ and $\tau_p$ such that steady state markups in labor and goods markets are neutralized, implying an efficient steady state equilibrium. We start out with the supply side of the economy and show how it pins down relative prices including the real exchange rate, as well as factor intensities of production. We then derive implications for consumption and investment aggregates, before we turn to the endogenous production structure of the economy, showing how a lower oil price affects the steady state. The initial steady state (before lower oil income) is conditional on sectoral productivity levels $A_T$ and $A_N$, initial oil income $O$, the net foreign asset position $B^*$, as well as structural parameters.[5] We normalize $A_T$ and $A_N$ to unity without loss of generality, and set $B^* = 0$ in the initial steady state. Consistent with Schmitt-Grohé and Uribe (2003) in their modeling of a stationary risk premium, it follows that also $B^* = 0$ in the new steady state with lower oil income. Initial oil income is set to target the average share of petroleum revenues in Norwegian GDP. The rest of the steady state follows recursively. Note, first, that the real consumer rate, the shadow value of capital, and the sectoral capital rental rates are given by $r = \beta^{-1} - 1$, $\mathcal{Q} = p_N^{\alpha_i - \alpha_c}$ and $r_T^k = r_N^k = [\beta^{-1} - (1-\delta)]\,\mathcal{Q}$, respectively. Firms' optimality conditions follow as:

$$\begin{aligned}
(1-\mu_T)\, p_N^{-\alpha_i} A_T k_T^{-\mu_T} &= \beta^{-1} - (1-\delta) \\
(1-\mu_N)\, p_N^{1-\alpha_i} A_N k_N^{-\mu_N} &= \beta^{-1} - (1-\delta) \\
\mu_T A_T k_T^{1-\mu_T} &= p_N \mu_N A_N k_N^{1-\mu_N}
\end{aligned}$$

These are three equations in the three endogenous variables $p_N$, $k_T$ and $k_N$. Direct substitution allows of to obtain closed-form solutions for these variables. The relative price of non-tradables, for example, is given by

$$p_N = \left[ \left[\beta^{-1} - (1-\delta)\right]^{\mu_T - \mu_N} \frac{\left[\mu_T^{\mu_T} (1-\mu_T)^{1-\mu_T} A_T\right]^{\mu_N}}{\left[\mu_N^{\mu_N} (1-\mu_N)^{1-\mu_N} A_N\right]^{\mu_T}} \right]^{\frac{1}{\mu_i}}, \tag{A.1}$$

where $\mu_i = \alpha_i \mu_N + (1-\alpha_i)\,\mu_T$ captures the implicit labor intensity in aggregate investments. With the relative price known, the sectoral capital intensities follow:

$$k_T = \left( \frac{(1-\mu_T)\, A_T}{\left[\beta^{-1} - (1-\delta)\right] p_N^{\alpha_i}} \right)^{\frac{1}{\mu_T}}, \qquad k_N = \left( \frac{(1-\mu_N)\, A_N p_N^{1-\alpha_i}}{\beta^{-1} - (1-\delta)} \right)^{\frac{1}{\mu_N}} \tag{A.2}$$

The solutions given by equations (A.1)-(A.2) show how $p_N$, $k_T$ and $k_N$ depend on productivity in the two sectors. But for our purpose, the important characteristic of these expressions is that they are all independent of oil income $O$. It follows that that the relative price $p_N$, and the capital intensities $k_T$ and $k_N$, remain the same in the old and the

[5] The steady state also includes nominal variables. We set all gross inflation rates to unity, $\Pi_c = \Pi_w = \Pi_T = \Pi_T = 1$.

new steady state. Sectoral output per worker, as well as the real exchange rate and the real wage, follow readily:

$$y_T = A_T k_T^{1-\mu_T} \qquad y_N = A_N k_N^{1-\mu_N} \qquad q = p_N^{-\alpha_c} \qquad \omega = q\mu_T A_T k_T^{1-\mu_T} \tag{A.3}$$

Thus, also these variable are unchanged across the two steady states. The same holds for the share of traded to non-traded goods in the consumption and investment aggregates, which only depend on the relative sector price:

$$\frac{C_T}{C_N} = \frac{1-\alpha_c}{\alpha_c} p_N \qquad\qquad \frac{X_T}{X_N} = \frac{1-\alpha_i}{\alpha_i} p_N$$

We now turn to steady state variables that depend on steady state oil income. As a point of departure, note that $C$, $K$, $Y_T$ and $Y_N$ are given by the following four equations:

$$\begin{aligned} p_N^{\alpha_c} C &= p_N^{\alpha_c} \omega L + r p_N^{\alpha_i} K + (O + r^* B^*) \\ (r+\delta)\, p_N^{\alpha_i} K &= (1-\mu_T)\, Y_T + (1-\mu_N)\, p_N Y_N \\ p_N^{\alpha_c} \omega L &= \mu_T Y_T + \mu_N p_N Y_N \\ Y_N &= \alpha_c p_N^{\alpha_c - 1} C + \alpha_i p_N^{\alpha_i - 1} \delta K \end{aligned}$$

The first equation is the steady state version of the budget constraint. The second and third equations aggregate capital and labor income across the two sectors. The fourth equation states that non-traded production is equal to the sum of non-traded consumption and investment demand. We can manipulate these four equations in order to obtain

$$C = \frac{1}{r\mu_c + \delta\mu_i} \left[ (r\mu_T + \delta\mu_i)\, p_N^{-\alpha_c} (O + rB^*) + (r + \delta\mu_i)\, \omega L \right]. \tag{A.4}$$

$\mu_c$ is defined as $\mu_c = \alpha_c \mu_N + (1-\alpha_c)\,\mu_T$, while $\mu_i$ is as defined above. Equation (A.4) shows exactly how consumption is increasing in oil revenues, foreign assets, and labor income. At the same time, we note that aggregate labor supply is given by

$$L = \left( \frac{C^{\frac{1}{\sigma}}}{\omega} \right)^{-\frac{1}{\varphi}}. \tag{A.5}$$

The system (A.4)-(A.5) are two equations in the two endogenous variables $C$ and $L$. While equation (A.4) is upward-sloping in the $(L, C)$-space, equation (A.5) is downward-sloping. The fixed point connecting these curves determines steady state consumption and labor.[6] Importantly, a fall in oil revenues $O$ makes the representative household poorer and, ceteris paribus, causes aggregate consumption to decline. This is illustrated by a downward shift in equation (A.4). Labor supply, in turn, increases as seen from (A.5). Higher labor income offsets some of the consumption fall due to lower oil income, but not all. This is natural given our assumption that both consumption and leisure are normal goods. Formally, we conclude that

$$\frac{\partial C}{\partial O} > 0 \qquad \text{and} \qquad \frac{\partial L}{\partial O} < 0.$$

[6]This fixed point is solved for numerically during simulations, as no closed form solution is available except in a few special cases.

With steady state consumption and labor pinned down, the aggregate capital stock follows next:

$$K = \frac{p_N^{\alpha_c - \alpha_i}}{r^c \mu_T + \delta \Phi_i} \left[ (1 - \mu_T) \omega L - (\mu_N - \mu_T) \alpha_c C \right] \tag{A.6}$$

Since we have already established that $L$ increases while $C$ falls, and given the assumption that $\mu_N > \mu_T$, it follows from equation (A.6) that two forces are pushing the aggregate capital stock up. First, a rise in aggregate labor supply. And second, (as we formally prove below), a reallocation towards the traded sector which is assumed to be more capital intensive. Now that we have solved for aggregate consumption and capital, the solutions for sectoral output levels follow readily:

$$Y_N = \alpha_c p_N^{\alpha_c - 1} C + \alpha_i \delta p_N^{\alpha_i - 1} K \tag{A.7}$$

$$Y_T = \frac{p_N^{\alpha_c} \omega L - \mu_N p_N Y_N}{\mu_T} \tag{A.8}$$

Using equations (A.7)-(A.8), we can establish that traded output relative to non-traded output must rise. To see this, note that

$$\frac{Y_T}{Y_N} = \frac{C_T + I_T - O}{C_N + I_N} = p_N \frac{1 - \alpha_c}{\alpha_c} \frac{1 + \frac{1-\alpha_i}{1-\alpha_c} p_N^{\alpha_i - \alpha_c} \frac{I}{C} - \frac{1}{(1-\alpha_c) p_N^{\alpha_c}} \frac{O}{C}}{1 + \frac{\alpha_i}{\alpha_c} p_N^{\alpha_i - \alpha_c} \frac{I}{C}}$$

$$= p_N \frac{1 - \alpha_c}{\alpha_c} \left[ \frac{1 + \frac{1-\alpha_i}{1-\alpha_c} p_N^{\alpha_i - \alpha_c} \frac{I}{C}}{1 + \frac{\alpha_i}{\alpha_c} p_N^{\alpha_i - \alpha_c} \frac{I}{C}} - \frac{\frac{1}{(1-\alpha_c) p_N^{\alpha_c}} \frac{O}{C}}{1 + \frac{\alpha_i}{\alpha_c} p_N^{\alpha_i - \alpha_c} \frac{I}{C}} \right].$$

We have already established that $\frac{\partial \frac{I}{C}}{\partial O} < 0$ and $\frac{\partial \frac{O}{C}}{\partial O} > 0$. Then, from the equation above, it follows that a sufficient (but not necessary) condition for $Y_T / Y_N$ to rise in response to the oil price fall is that $\alpha_c > \alpha_i$. Put differently, a permanent decline in oil revenues leads to a rise in tradable over non-tradable output as long as consumption has a higher non-tradable share than investment. There are two forces in operation: first, lower oil income implies that less traded goods are available for domestic use. The production structure must be tilted in the direction of relatively more tradable production in order to compensate for this, implying that $O/C$ declines. Second, the economy has become more capital intensive, implying that $I/C$ must rise. This also pulls $Y_T / Y_N$ up as long as $\alpha_c > \alpha_i$, which is the relevant calibration in most economies. A special case in this aspect, however, is the Norwegian economy where $\alpha_c = 0.43$ and $\alpha_i = 0.57$. We stress, however, that even in this special case the ratio $\frac{Y_T}{Y_N}$ is still decreasing in $O$ under all reasonable calibrations. That is, our baseline calibration of non-traded shares in demand, based on Norwegian data, does not turn around the conventional relationship between $\frac{Y_T}{Y_N}$ and $O$. This completes our description of the steady state implications of a permanent fall in oil income.

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