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# The Effects of Total Factor Productivity and Export Shocks on a Small Open Economy with Unemployment

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## Abstract

The paper analyzes the dynamic effects of a supply side shock and a demand side shock, which hit an open economy with unemployment. The supply side shock is modeled as a reduction in total factor productivity, whereas the demand side shock is caused by a drop in exports. The model builds upon the small one-sector two-good open economy framework described in Turnovsky (2000, ch. 11.3). In contrast to this standard framework, in which Walrasian labor markets are assumed, search unemployment and wage bargaining are introduced, and unemployment results from time consuming and costly matching of vacancies with searching agents. Using a plausible calibration of the model, the dynamic adjustments of unemployment, output, and other economic key variables are analyzed. We find that a negative export shock primarily has effects on consumption and welfare, but not on unemployment and output, whereas the supply side shock leads to considerable responses of unemployment, output, consumption and welfare. If both shocks together hit the economy, the changes in consumption and welfare almost double.

*Keywords:* total factor productivity shock, export shock, search unemployment, open economies

**JEL classification:** F41, F47, J64

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## 1. Introduction

The 2007 - 2009 global financial crisis, which many economists view as the worst financial crisis since the one related to the Great Depression in the 1930s, started 2007 with the burst of the US housing bubble which quickly damaged financial institutions globally. The financial crisis escalated in September 2008 and has provoked an unprecedented contraction of economic activity as credit supply fell (“credit crunch”) and international trade declined. Industrial production plummeted in the fourth quarter of 2008 and continued to fall rapidly in the first part of 2009. Global GDP is estimated to have contracted by 6.25% (annualized) in the fourth quarter of 2008 and to have fallen almost as fast in the first quarter of 2009 (see IMF (2009a, ch. 1)). In 2009, output in advanced economies contracted by 3.2% (see IMF (2010, TableA1)).

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The global financial crisis affected economies in at least two important ways. First, the financial crisis led to a “credit crunch”, and the efficiency of financial intermediation suffered substantially. As the financial system may not be able to allocate loanable funds as productively as before the crisis and high-productivity firms may go under for lack of financing, the efficiency of the production process reduces and total factor productivity (TFP) falls (see IMF (2009b, ch. 4)). This view is supported by several recent studies (see, e.g., Estevão and Severo (2010) Haugh, Ollivaud, and Turner (2009), Meza and Quintin (2005) and Cole, Ohanian, and Leung (2005)).<sup>2</sup>

Second, the worldwide economic downturn reduced international trade. Whereas the volume of world trade grew by 7.3% and 3% in 2007 and 2008, respectively (see IMF (2009b, ch. 1)), in the half-year encompassing the last quarter of 2008 and the first quarter of 2009 the annualized drop in world imports was more than 30%, with roughly equal declines experienced by advanced and emerging economies (see IMF (2010, ch. 4)). Export oriented countries suffered a collapse of exports by 30% and more.

Another example of a negative total factor productivity shock are earthquake disasters as recently occurred in Japan or Haiti.

An important issue in conjunction with such shocks is how unemployment is affected. This paper focuses on unemployment dynamics in open economies in the aftermath of such a crisis. Aside from unemployment dynamics, we investigate how other key economic variables such as capital, output, and consumption adjust and how economic welfare is affected.

To be able to analyze the dynamics of unemployment, we have to depart from the standard neoclassical approach with a Walrasian labor market, in which, by definition, unemployment does not exist, labor adjusts instantaneously, and the labor market always clears by proper adjustments of the real wage. We therefore augment and modify the standard representative agent model of a one-sector, two-good small open economy of the Turnovsky and Sen (1991) type by introducing search unemployment a la Mortensen and Pissarides<sup>3</sup> and wage bargaining in a similar way as in the closed economy models of Shi and Wen (1997, 1999) and Heer (2003), where unemployment results from time consuming and costly matching of vacancies with agents who search for a job.

To date, there is little literature on the dynamics of open economies in the presence of search unemployment. Papers employing static trade models with search unemployment include Davidson, Martin, and Matusz (1991, 1999). Şener (2001) explores impacts of international trade on wages and unemployment in presence of skilled and unskilled workers and job-matching frictions along a balanced growth path. In a dynamic general equilibrium model of R&D-generated growth, Moore and Ranjan (2005) link sectoral search unemployment with trade theory and analyze the transition dynamics of unemployment and wage inequality in the case of skill based technological change. Azariadis and Pissarides (2007) apply the framework of an

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<sup>2</sup>However, Petrosky-Nadeau (2010) comes to the opposite conclusion that TFP increases after a financial crisis, because the least productive jobs are destroyed.

<sup>3</sup>See Pissarides (2000) for an overview.

overlapping generations model to an open economy to analyze the response of the domestic unemployment rate to total factor productivity shocks. All these models differ substantially from the small open economy framework, and their scope is completely different from the issue analyzed in this paper. With respect to the analytical framework used in the literature so far, one rare exception is Shi (2001), who combines the Turnovsky and Sen (1991) framework and search unemployment to study the effects of a tariff under exogenous and endogenous terms of trade.

Our model differs from Shi (2001) and the closed economy versions of Shi and Wen (1997, 1999) and Heer (2003) in several important aspects. First, the representative agent's utility function is assumed to be non-separable with respect to consumption and leisure, allowing for richer consumption dynamics. Second, we introduce investment adjustment costs, giving rise to a Tobin  $q$  theory of investment. This enriches the dynamics and allows us to investigate the time profile of stock prices (the price of capital). Third, we depart from the assumption that the production function is Cobb-Douglas and use the more general constant elasticity of substitution (CES) specification. The reason for doing this is twofold. On the one hand recent empirical findings suggest that the elasticity of substitution is well below unity (see Papageorgiou (2008) and Chirinko (2008)). On the other hand, it allows us to analyze how the economy's transition changes with the degree of production flexibility.

We separately study (i) a negative export shock and (ii) a negative total factor productivity (TFP) shock. Finally, we combine both shocks and study how economic activity is reduced.

The macroeconomic equilibrium we derive is described by a dynamic system involving the interaction between the allocation of labor, the market price of capital, the accumulation of capital, unemployment, and the accumulation of net foreign assets. The complexity of the model requires its dynamics and the steady-state changes to be analyzed using numerical simulations. This allows us to perform a comprehensive sensitivity analysis with respect to structural parameters as the elasticity of substitution in production, the export-GDP ratio and the status of the economy as a creditor or debtor country.

We find that a pure negative export shock has little effect on GDP and unemployment, as the real exchange rate adjusts, but reduces consumption and welfare, and that the major part of adjustment occurs on impact. In contrast, a pure negative TFP shock, impinging on output, leads to considerable short-run unemployment as well as short-run consumption and welfare losses, followed by transitional dynamics, and unemployment shows hysteresis, i.e. it remains on a permanently higher long-run level, whereas long-run output, consumption and welfare are permanently lower. Our findings are in line with recent estimations of output and consumption losses due to the global financial crisis, and our model provides a theoretical underpinning of recent empirical work (e.g., Cerra and Saxena (2008), Furceri and Mourougane (2009), IMF (2009b)). Further, our analysis supports the empirical result that countries that suffer a financial crisis have done worse in terms of GDP declines than countries that suffer only a decline in exports.

The remaining part of the paper is structured as follows: Section 2 sets up the dynamic model. The model is calibrated in section 3, and numerical simulations of the shocks as well as sensitivity analysis are

performed. Section 4 summarizes our findings and concludes.

## 2. Analytical Framework

The model introduces search into the semi-small open economy model of Turnovsky (2000, ch. 11.3). Four sectors can be distinguished: households, firms, the government, and the international sector, which we consider in turn.

### 2.1. Households

The domestic economy is populated by many identical households. Each household consists of a continuum of agents with a fixed measure. Each household is endowed with one unit of time, which can be used for labor (supply)  $l^s$ , search,  $s$ , or leisure,  $L = 1 - l^s - s$ . Agents who are searching are called unemployed agents. Thus,  $l^s$  can be interpreted as time used for working (employment),  $s$  as the time used for searching (unemployment), and  $L$  as time enjoying leisure. The labor force is defined as  $l^s + s$ , and the unemployment rate as  $s/(l^s + s)$ . Besides leisure, each household consumes a consumption bundle  $c$ , containing the domestically produced good,  $c_d$ , and the imported consumption good,  $c_f$ , which are combined according to the linearly homogenous aggregator (sub-utility) function

$$c = \left( \kappa^{\frac{1}{\psi}} c_d^{\frac{\psi-1}{\psi}} + (1 - \kappa)^{\frac{1}{\psi}} c_f^{\frac{\psi-1}{\psi}} \right)^{\frac{\psi}{\psi-1}} \quad (1a)$$

where  $\kappa$  is the weight of the domestically produced good ( $0 < \kappa < 1$ ), and  $\psi$  denotes the intratemporal elasticity of substitution between the domestic and the foreign consumption good.

The representative household earns wage income from labor, interest income from holding internationally traded bonds  $b$  (denoted in terms of the foreign good), and receives the after-tax profits  $\pi$  of the representative firm he owns. He uses his income to purchase the consumption bundle  $c$  at the price  $P$ , to accumulate bonds,  $b$ , and to pay lump-sum taxes  $T$ . Consequently, his flow budget identity is

$$\dot{b} = \frac{1}{p} [\pi + prb + (1 - \tau_w)wl^s - Pc - T] \quad (1b)$$

where  $p$  denotes the real exchange rate (the relative price of the imported good in terms of the domestic good),  $r$  is the exogenously given world interest rate,  $w$  the wage rate, and  $\tau_w$  the labor income tax rate. The variable  $P$  denotes the price of the consumption bundle in terms of the domestic good and is defined as

$$P \equiv (1 + \tau_c) (\kappa + (1 - \kappa)p^{1-\psi})^{\frac{1}{1-\psi}} \quad (1c)$$

where  $\tau_c$  is the consumption tax rate.<sup>4</sup>

<sup>4</sup>The expression for  $P$  is derived by solving the expenditure minimization problem  $\min_{c_d, c_f} (1 + \tau_c)c_d + (1 + \tau_c)pc_f$  s. t.  $c = 1$ , where  $c$  is defined in (1a). That is,  $P$  denotes the minimum expenditure in terms of the domestic good necessary to buy one unit of  $c$ . The rates of consumption follow then as  $c_d = \kappa((1 + \tau_c)/P)^{-\psi} c$  and  $c_f = (1 - \kappa)((1 + \tau_c)p/P)^{-\psi} c$ . See Obstfeld and Rogoff (1996), pp. 226.

A distinguishing feature of the model is that labor (employment)  $l$  changes only gradually according to

$$\dot{l}^s = \phi s - \zeta l^s \quad (1d)$$

where  $\phi$  denotes the job finding rate, which the individual agent takes as given, and  $\zeta$  is the exogenously given rate of job separation.<sup>5</sup>

The representative household derives utility from consumption  $c$  and leisure  $L$ .<sup>6</sup> He maximizes the intertemporal iso-elastic utility function  $W$

$$W \equiv \int_0^{\infty} \frac{1}{\epsilon} [c(1 - l^s - s)^{\theta}]^{\epsilon} e^{-\beta t} dt, \quad \theta \geq 0, 1 > \epsilon\theta, 1 > \epsilon(1 + \theta) \quad (2)$$

by choosing the rates of consumption,  $c$ , and search,  $s$ , and the rates of bonds and labor accumulation, subject to the flow budget constraints (1b) and (1d), and the given initial stocks of traded bonds,  $b(0) = b_0$ , and labor,  $l^s(0) = l_0^s$ , respectively.  $\beta$  denotes the agent's rate of time preference, taken to be constant. The intertemporal elasticity of substitution w. r. t. the consumption bundle  $c$  is equal to  $1/(1 - \epsilon)$ , and  $\theta$  denotes the elasticity of leisure. The household's first order conditions are given by

$$c^{\epsilon-1} (1 - l^s - s)^{\epsilon\theta} = \lambda \frac{P}{p} \quad (3a)$$

$$\theta c^{\epsilon} (1 - l^s - s)^{\epsilon\theta-1} = \gamma \phi \quad (3b)$$

$$\beta - \frac{\dot{\lambda}}{\lambda} = r \quad (3c)$$

$$\frac{\lambda(1 - \tau_w)w}{\gamma p} + \frac{\dot{\gamma}}{\gamma} - \zeta = \beta + \phi \quad (3d)$$

and the transversality conditions

$$\lim_{t \rightarrow \infty} \lambda b e^{-\beta t} = \lim_{t \rightarrow \infty} \gamma l^s e^{-\beta t} = 0 \quad (3e)$$

where  $\lambda$  is the shadow value of wealth in the form of internationally traded bonds, i. e., the marginal utility of wealth, and  $\gamma$  is the shadow price of employment. Condition (3a) equates the marginal utility of the consumption bundle to the marginal utility of wealth, measured in terms of the consumption bundle. Equation (3b) equates the marginal cost of search (i. e. the (dis)utility) to the marginal benefit of search, i. e. the rate of finding a job times the value of employment. The dynamic equation (3c) requires the rate of return on consumption to be equal to the rate of return on bonds, and gives rise to the zero-root property (see Sen (1994)). For an interior solution, we require  $\lambda$  to remain constant ( $\lambda = \bar{\lambda}$ ), and this in turn requires that the the agent's rate of time preference has to be equal to the exogenously given world interest rate,  $\beta = r$ . The dynamic no-arbitrage condition (3d) requires the rate of return on employment, comprising the "dividend

<sup>5</sup>Following Shi and Wen (1997, 1999), and Heer (2003), the job destruction rate is assumed to be exogenous to not further complicate the model. Moreover, as it is discussed in Pissarides (2000, ch. 2), the dynamics in case of an endogenous job destruction rate are similar to those derived in a model where the job separation rate is exogenous.

<sup>6</sup>In contrast to Shi and Wen (1997, 1999) and Heer (2003), the instantaneous utility function is not separable in consumption and leisure. Our specification is more general and complicates the model, as it gives rise to richer dynamics.

yield” of employment,  $\lambda(1 - \tau_w)w/(\gamma p)$ , the “capital gain”  $\dot{\gamma}/\gamma$  and the loss due to job destruction  $\zeta$ , to be equal to the “effective” discount rate  $\beta + \phi$ . Finally, in order to ensure that the agent’s intertemporal budget constraint is met, the transversality conditions (3e) must hold.

The optimality conditions for consumption and search (3a) and (3b) can be solved to obtain the short-run solution for search

$$s = s(l^s, \bar{\lambda}, p, \gamma, \phi); \quad s_l = -1, s_\lambda < 0, s_p > 0, s_\gamma > 0, s_\phi > 0 \quad (4)$$

as a function of labor, the marginal utility of wealth, the real exchange rate, the shadow price of employment, and the job finding rate. Solving the dynamic no-arbitrage equation (3d) by integration and invoking the transversality condition (3e), we get

$$\gamma(t) = \int_t^\infty \frac{\bar{\lambda}(1 - \tau_w)w(\tau)}{p(\tau)} e^{-\int_t^\tau (\zeta + \beta + \phi(\omega))d\omega} d\tau \quad (5)$$

The shadow price of employment, i. e. the value of a job,  $\gamma$ , expressed in terms of utility, equals the discounted value of the agent’s flow of the net real wage  $(1 - \tau_w)w/p$ , expressed in terms of utility (therefore multiplied by  $\lambda$ ). We will come back to these two equations in subsection 3.4.3 when we discuss the unemployment dynamics.

## 2.2. Firms

The economy comprises also a large number of identical firms. Firms produce a domestic good,  $y$ , by combining capital,  $k$ , and labor, which is demanded at an amount  $l^d$ , by means of a constant elasticity of substitution (CES) production function

$$y = A[\alpha k^{-\rho} + (1 - \alpha)(l^d)^{-\rho}]^{-\frac{1}{\rho}}, \quad -1 \leq \rho < \infty, 0 < \alpha < 1 \quad (6a)$$

where  $A$  is a scale parameter, summarizing total factor productivity, and  $\alpha$  denotes the share of capital in production. The constant elasticity of substitution is given by  $\sigma \equiv 1/(1 + \rho)$ . Capital accumulation is due to convex installation costs, resulting in a total investment cost function

$$\Phi(I, k) = I + h \frac{I^2}{2k} = I \left( 1 + \frac{h I}{2k} \right) \quad (6b)$$

where adjustment costs are convex in  $I$  and proportional to the rate of investment per unit of installed capital,  $I/k$ . Letting  $\delta$  denote the rate of depreciation of the capital stock, the rate of capital accumulation is given by

$$\dot{k} = I - \delta k \quad (6c)$$

Workers separate from a job at rate  $\zeta$ . The individual firm takes the rate  $\varphi$  of filling a vacancy  $v$  as given. Hence, the firm’s employment,  $l^d$ , follows

$$\dot{l}^d = \varphi v - \zeta l^d \quad (6d)$$

The firm has to pay a cost for maintaining a number of job vacancies equal to  $mv$ . This cost includes advertising costs (Pissarides (1987)), and can also be thought as a hiring/recruiting cost (Pissarides (1986)),

Mortensen and Pissarides (1994)), and/or as the cost of a human resources division. The firm's operating profit (capital earnings)  $y - wl^d - mv$  is taxed at rate  $\tau_k$ . Thus, the firm's net profits are given by

$$\pi = (1 - \tau_k)(y - wl^d - mv) - \Phi(I, k) \quad (6e)$$

The firm's objective is to maximize the value of the firm, i.e. the present value of profits,  $V$

$$V \equiv \int_0^{\infty} \pi(t) e^{-\int_0^t r_d(z) dz} dt \quad (7)$$

by choosing investment  $I$ , vacancies  $v$ , and the rates of capital accumulation and labor  $l^d$ , subject to equations (6) and the initial stocks of capital and labor,  $k(0) = k_0$  and  $l^d(0) = l_0^d$ .  $r_d$  denotes the domestic interest rate. Because capital is perfectly mobile and domestically issued and foreign bonds are perfect substitutes, uncovered interest rate parity holds, and the domestic interest rate is equal to the foreign interest rate plus the rate of depreciation of the real exchange rate,

$$r_d = r + \frac{\dot{p}}{p}$$

Solving the firm's optimization problem gives rise to the following first order conditions:

$$1 + h \frac{I}{k} = q \quad (8a)$$

$$(1 - \tau_k)m = \xi \varphi \quad (8b)$$

$$\frac{(1 - \tau_k)\alpha A^{-\rho} \left(\frac{y}{k}\right)^{1+\rho}}{q} + \frac{\dot{q}}{q} + \frac{(q-1)^2}{2qh} - \delta = r + \frac{\dot{p}}{p} \quad (8c)$$

$$\frac{(1 - \tau_k)(1 - \alpha) A^{-\rho} \left(\frac{y}{l^d}\right)^{1+\rho}}{\xi} + \frac{\dot{\xi}}{\xi} - \frac{(1 - \tau_k)w}{\xi} - \zeta = r + \frac{\dot{p}}{p} \quad (8d)$$

$$\lim_{t \rightarrow \infty} qk e^{-\int_0^t [r(z) + \dot{p}(z)/p(z)] dz} = \lim_{t \rightarrow \infty} \xi l^d e^{-\int_0^t [r(z) + \dot{p}(z)/p(z)] dz} = 0 \quad (8e)$$

where  $q$  is the market price of installed capital and  $\xi$  denotes the shadow price of labor. Equation (8a) determines the rate of investment,  $I$ , and gives rise to a Tobin  $q$  theory. Given the capital stock, the higher  $q$ , the more the firm will invest. Equation (8b) equates the marginal cost of vacancy to its marginal benefit. The dynamic no-arbitrage relation (8c) requires that the rate of return on capital is equal to the domestic interest rate. The rate of return on domestic capital comprises four terms. The first is the "dividend yield", the second the capital gain, the third reflects the fact that a benefit of a higher capital stock is to reduce the installation costs (which depend on  $I/k$ ) associated with new investment, whereas the fourth element represents a loss due to the depreciating capital stock. The no-arbitrage relation (8d) equates the rate of return on labor, comprising a "dividend yield", a "capital gain", and two losses due to wage payments and job destruction, to the domestic interest rate. Finally, the transversality conditions (8e) must hold.

### 2.3. Goods Market Clearing

Domestic goods market equilibrium requires that output is allocated to domestic consumption, government spending on the domestic good,  $g$ , investment expenditures, exports, and vacancy costs, i. e.

$$y = c_d + g + \Phi(I, k) + Z(p) + mv \quad (9)$$

where  $Z(p)$  denotes exports as a function of the real exchange rate. We shall assume that export demand is a function with constant price elasticity  $\varepsilon$

$$Z(p) = Z_0 p^\varepsilon \quad (10)$$

where  $Z_0$  represents an exogenous shift parameter. Goods market clearance (9) is maintained by proper adjustments of the real exchange rate,  $p$ .

### 2.4. Matching and Wage Determination

As in Shi and Wen (1997, 1999), and Heer (2003), labor markets are subject to frictions and are characterized by two-sided search. Matching vacancies with searching agents is a time-consuming process. To simplify notation,  $v$  and  $s$  also denote the aggregate numbers of vacancies and searching agents, respectively. We assume a constant returns to scale matching technology of the Cobb-Douglas form

$$M(v, s) = Bv^\chi s^{1-\chi}, \quad B > 0, 0 < \chi < 1 \quad (11)$$

Thus, matches per unemployed agent can be expressed as  $\phi = B(v/s)^\chi$ , and matches per vacancy as  $\varphi = B(v/s)^{\chi-1}$ . Hence, the rates of finding a job and of filling a vacancy are endogenously determined, whereas households and firms take them as given. Defining  $x \equiv v/s$  as the vacancy-unemployment ratio, we can write

$$\phi(x) = Bx^\chi, \quad \varphi(x) = Bx^{\chi-1}$$

where we see that matches per searching agent  $\phi$  are an increasing function in the vacancy-unemployment ratio, whereas matches per vacancy are a decreasing function in  $x$ .

Once an unemployed agent is matched with a vacancy, the agent and the firm negotiate the time path of the agent's wage rate  $w$ . Wages are measured in terms of the domestic good and are determined by Nash bargaining. Hiring an additional worker will increase the firm's surplus by  $(\partial y / \partial l - w)$ . By accepting a job offer, the household's income rises by  $(1 - \tau_w)w$ , the value of which in terms of utility is  $(\bar{\lambda}/p)(1 - \tau_w)w$ . On the other hand, an increase in labor reduces agent's utility by  $\theta c^\varepsilon (1 - l^s - s)^{\theta\varepsilon-1}$ . Noting that from (3a)  $\bar{\lambda}/p = c^{\varepsilon-1} (1 - l^s - s)^{\theta\varepsilon}$ , we can express the worker's net gain in terms of the domestic good as  $w - \frac{\theta P c}{(1-l^s-s)(1-\tau_w)}$ , where the second term can be interpreted as the household's reservation wage. Hence, the Nash bargaining solution solves

$$\max_w \left( (1 - \alpha) A^{-\rho} \left( \frac{y}{l^d} \right)^{1+\rho} - w \right)^{1-\varrho} \left( w - \frac{\theta P c}{(1-l^s-s)(1-\tau_w)} \right)^\varrho$$

The parameter  $0 < \varrho < 1$  measures the bargaining power of workers. The solution of the Nash bargaining game gives the wage rate

$$w = \varrho(1 - \alpha)A^{-\rho} \left( \frac{y}{l^d} \right)^{1+\rho} + (1 - \varrho) \frac{\theta P c}{(1 - l^s - s)(1 - \tau_w)} \quad (12)$$

The wage rate is a weighted average of the marginal product of labor and the agent's reservation wage. The wage lies thus between the marginal product of labor and the marginal rate of substitution of leisure for consumption. This is in sharp contrast to the standard model with a neoclassical labor market, where the wage rate equals both the marginal product of labor and the marginal rate of substitution. Note that, *ceteris paribus*, the wage rate depends positively on the price for the consumption bundle,  $P$ , which in turn is an increasing function of the real exchange rate,  $p$  (see (1c)).

### 2.5. Macroeconomic Equilibrium

The macroeconomic equilibrium is defined as follows (see Shi and Wen (1997, 1999), Heer (2003)).

**Definition.** The competitive search equilibrium is a collection of decision rules  $\{c, s, b, l^s, l^d, I, v, k\}$  and prices  $\{q, w, p\}$  such that

1. Individual variables equal (average) aggregate variables.
2. Households maximize their utility (2) subject to (1).
3. Firms maximize the value of the firm (7) subject to (6).
4. Wages are given by (12).
5. The market price of capital evolves according to (8c).
6. The real exchange rate  $p$  adjusts properly to continuously clear the domestic goods market (9).
7. Capital and net foreign assets accumulate according to (6c) and (14b), respectively.
8. Agents do not take into account the effect of their decisions on the matching rates  $\phi$  and  $\varphi$ . In equilibrium,  $\varphi v = \phi s$ .
9. Employment evolves according to (1d).

Since the flow of workers in and out of employment are equal to each other in an symmetric equilibrium, that is  $\varphi(x) = \phi(x)s$ , equations (1d) and (6d) tell us that the supply of labor equals the demand for labor, i. e.  $l^s = l^d = l$ . Note that this market clearing condition does not pin down the wage rate  $w$  as in the neoclassical framework. Rather, the wage rate is a result of bargaining and follows from equation (12).<sup>7</sup>

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<sup>7</sup>On this issue, see Shi and Wen (1999, p. 465).

## 2.6. Current Account

The stock of net foreign assets (NFA) in the economy is defined as  $n \equiv b - a$ . Subtracting the government's flow budget constraint<sup>8</sup>

$$\dot{a} = \frac{1}{p}[g + pra - \tau_k(y - wl - mv) - \tau_w wl - \tau_c(c_d + pc_f) - T] \quad (13)$$

from (1b) yields thus the national budget constraint

$$\dot{n} = \frac{1}{p}[y - c_d - pc_f - g - \Phi(I, k) - mv + prn] \quad (14a)$$

i. e. the economy's current account. Inserting (9) into (14a), the current account can equivalently be written as

$$\dot{n} = \frac{Z(p)}{p} - c_f + rn \quad (14b)$$

where  $Z(p)/p - c_f$  is the trade balance, expressed in terms of the foreign good. Combining the transversality conditions for households and the government gives rise to the economy's intertemporal budget constraint

$$\lim_{t \rightarrow \infty} n e^{-rt} = 0 \quad (14c)$$

## 3. Numerical Simulations

Because both the steady state equations and the dynamics of the model are analytically intractable, we resort to numerical simulations.<sup>9</sup>

### 3.1. Benchmark calibration

The model is calibrated to reflect some key features of OECD countries.<sup>10</sup> Table 1 summarizes the parameters on which the simulations are based. Time is measured in years.

The world interest rate,  $r$ , and the rate of time preference,  $\beta$ , are set equal to 0.04, a value which is non-controversial. The preference parameter  $\epsilon$  is set equal to  $-1.5$  and corresponds to an intertemporal elasticity of substitution of 0.4. Following Backus, Kehoe, and Kydland (1994), the consumption aggregator function (1a) is assumed to have an intratemporal elasticity of substitution between the domestic and foreign good of 1.5, implying that domestic and foreign goods are substitutes in consumption. The share of capital in production is set equal to  $\alpha = 1/3$  and is standard. The rate of depreciation equals 0.05, a value that is usually assumed, see, e. g., Chatterjee and Turnovsky (2007). The initial productivity parameter  $A$  is set equal to unity. The elasticity of leisure,  $\theta$ , is the key determinant of the equilibrium labor-leisure allocation and has been set to ensure that this is empirically plausible. A value of 1 yields an equilibrium fraction of time

<sup>8</sup>For the government to remain solvent, we require  $\lim_{t \rightarrow \infty} a e^{-rt} = 0$ .

<sup>9</sup>The derivation and linearization of the dynamic system as well as the steady state are reported in an appendix, available upon request.

<sup>10</sup>Many OECD countries are well-suited to be represented by the semi-small open economy framework, that is, they face a given world interest rate, but an endogenous real exchange rate. E. g., member states of the Euro area normally not have influence on the Euro zone interest rate.

Table 1: The Benchmark Economy

Preference parameters	$\beta = 0.04, \epsilon = -1.5, \theta = 1, \psi = 1.5,$ $\kappa = 0.2, 0.5, 0.8$
Production parameters	$A = 1, \sigma = 0.5, 1, 1.25, \alpha = 1/3,$ $\delta = 0.05, h = 12$
Exogenous parameters	$r = 0.04, \zeta = 0.125, \rho = 0.5,$ $\chi = 0.6, B = 1, m = 0.4, \varepsilon = 4$
Initial stock of NFA	$n_0 = 0.1, 0, -0.1$
Policy instruments	$g = 0.08, \tau_k = 0.3, \tau_w = 0.3, \tau_c = 0.2$
Shock	$A = 0.97, Z_0$ drops by 30%

devoted to leisure ( $1 - l - s$ ) of around 0.7, consistent with the empirical evidence. The choice of adjustment costs is less obvious and  $h = 12$  lies within the range of 10 to 16 generally assumed in the literature.<sup>11</sup>

The parameter  $\zeta$  is set equal to an annual job separation rate of 12.5% which is in accordance with recent findings of Hobijn and Şahin (2009).<sup>12</sup> The bargaining power of workers and firms is assumed to be equal, therefore we choose  $\rho = 0.5$ .<sup>13</sup> The values of  $\chi$  and  $B$  are taken from Shi and Wen (1999) and Heer (2003). The vacancy cost  $m$  is set to imply an empirically plausible unemployment rate. Setting  $m = 0.4$  results in a steady state unemployment rate  $s/(s + l)$  of roughly 8%, a value close to the average European Union and the average OECD-Europe unemployment rate in 2006, see OECD (2009).

The initial real exchange rate is normalized to unity ( $p_0 = 1$ ), and the export shift parameter  $Z_0$  is adjusted in a way to equilibrate the domestic goods market. The elasticity of exports with respect to the real exchange rate,  $\varepsilon$ , is set equal to 4.<sup>14</sup>

The level of government spending  $g$  is chosen in a way to obtain an empirically plausible ratio of government spending to GDP of about 0.2. The tax rates on gross operating profits (capital income), labor, and consumption are chosen in accordance with recent empirical evidence and earlier search models.<sup>15</sup> They

<sup>11</sup>Ortigueira and Santos (1997) show that the speed of convergence is sensitive to  $h$ , and choose  $h = 16$  on the grounds that it generates a speed of convergence of around 2 percent per annum, consistent with much empirical evidence. Auerbach and Kotlikoff (1987) assume  $h = 10$ , and recognize that this is at the low value of estimates, while Barro and Sala-i-Martin (2003) propose a somewhat larger value. We also performed sensitivity analysis by varying  $h$  between 5 and 25 with little change in results.

<sup>12</sup>In contrast to Hobijn and Şahin (2009), who estimated monthly job separation rates for 23 OECD countries,  $\zeta$  is expressed on an annual basis. For a lot of countries (e.g. Belgium, Czech Republic, Germany, France, Netherlands, Portugal, Poland, USA) the monthly job separation rate is close to 1%, translating into an annual rate of roughly 12.5%. Moreover, varying  $\zeta$ , adjusting  $m$  properly to yield a steady state unemployment rate of around 8%, shows almost no effects on economic key variables, and in particular on welfare.

<sup>13</sup>Shi and Wen (1999) and Heer (2003) calibrate their models with a slightly different value (0.4).

<sup>14</sup>We are aware that estimates of export elasticity w.r.t. the real exchange rate (RER) are much lower. They range between close to zero and 1.6, see, e.g., Colacelli (2008), Hooper, Johnson, and Marquez (2000), Bayoumi (1999), and others. The reason for choosing a value of  $\varepsilon = 4$  rather than, say, unity is that the model should give rise to reasonable exchange rate movements. Because the model does not allow for price rigidities, the RER has to adjust to clear the goods market. If we would set  $\varepsilon = 1$ , say, the combined export-TFP shock we analyze would result in unrealistic RER movements (on impact the RER would change by roughly 29%), causing implausible welfare losses.

<sup>15</sup>Shi and Wen (1999) choose  $\tau_k = \tau_w = 0.3$  in their simulations. Elschner and Vanborren (2009) calculate an effective average corporate tax rate of 22.3% for the EU27 and of 26.3% for the EU15, but detect considerable dispersion (e.g., the lowest value was found in Bulgaria (8.8%), and the highest in Germany (35.5%)). Carey and Tchilinguirian (2000) calculated average effective tax rates in OECD countries. The tax rate on gross operating surplus for the OECD average was 26.6%, while for the

provide a reasonable basis for numerical simulations.

There are three crucial parameters. First, we consider the degree of export dependence of the economy as countries differ substantially in their export-output (and import-output) ratios.<sup>16</sup> It is a stylized fact that the smaller an economy geographically, the more open it is with respect to trade.<sup>17</sup> Also, looking at data confirms that a country's export-output and import-output ratios are similar, i. e., that countries with a high export-output ratio tend to have a high import-output ratio, too, see OECD (2009). Moreover, the steady-state zero current account condition implies that in steady state the value of exports differs from imports only by an amount equal to foreign (net) interest earnings. Thus, in terms of our model varying the share of exports in GDP can be achieved by varying the import-output ratio. Therefore, the parameter  $\kappa$ , measuring the weight of the domestic good in the consumption basket, is assumed to take the values 0.2, 0.5 and 0.8, corresponding with an initial export-output ratio of roughly 0.5, 0.3 and 0.13, respectively. Taking into account that the model abstracts from imported inputs to keep the analysis more tractable, our values seem to span a plausible range.

Second, we characterize the degree of flexibility in production in terms of the elasticity of substitution, varying  $\sigma$  between 0.5 and 1.25.<sup>18</sup> Empirical evidence on the elasticity of substitution in production is not unique.<sup>19</sup> On this basis, and given its prominent role in macrodynamics in general and in modern growth theory in particular, it seems reasonable to take the Cobb-Douglas specification ( $\sigma = 1$ ) as a benchmark and to vary the elasticity between 0.5 and 1.25, thereby spanning plausible values.

Third, countries differ with respect to their international investment position. Some countries as Germany and France are creditor countries, others like Portugal and Italy are debtor countries. To take the NFA status into account, we let the initial stock of net foreign assets vary between +0.1 and -0.1, spanning thus plausible NFA-GDP ratios between roughly +0.25 and -0.25.<sup>20</sup>

### 3.2. Initial Equilibria

Table 2 summarizes the initial equilibria corresponding to the benchmark parameter values and for alternative values of  $\sigma$ ,  $\kappa$  and the initial NFA position. Of these alternative values we identify the values  $\sigma = 1$ ,  $\kappa = 0.5$ ,  $n_0 = 0$  (set in bold) as a plausible benchmark. The critical equilibrium ratios are all in their respective ranges: The equilibrium capital (value)-output ratio is around 2.9, whereas the consumption

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G7 it was 30.7%. For labor, the tax rates were 33.4% and 29.8%, respectively. The tax rate on consumption was 17.1% for the OECD average and 18.7% for the EU average. Note that earlier studies as Mendoza, Razin, and Tesar (1994) estimated higher tax rates. As a matter of fact, in the last years tax rates fell.

<sup>16</sup>E. g., the ratio of exports of goods and services to GDP in 2007 was 0.26 for France, 0.27 for the UK and Spain, 0.30 for Italy, 0.33 for Portugal, 0.46 for Norway, 0.47 for Germany, 0.83 for Belgium, but only 0.18 for Japan. [Own calculations, based on data from Eurostat.]

<sup>17</sup>For example, in 2007 Belgium and Luxembourg, both being very small, showed export-GDP ratios of 0.83 and 1.77, respectively.

<sup>18</sup>The values of  $\sigma = 0.5, 1, 1.25$  correspond to  $\rho = 1, 0, -0.2$ .

<sup>19</sup>E. g., whereas Berndt (1976) found support for the Cobb-Douglas specification, Duffy and Papageorgiou (2000) estimated an elasticity of substitution above unity for high income countries. Recently, Papageorgiou (2008), using a frontier empirical methodology and a new data set, estimated  $\sigma \approx 0.7$ , and Chirinko (2008) found even lower values for  $\sigma$ . For further empirical work on the estimation of the elasticity of substitution, see Table 1 in Chirinko (2008).

<sup>20</sup>E. g., in 2006, the ratio was 0.28 for Germany, 0.06 for France, -0.21 for Austria and -0.06 for Italy. [Own calculations, based on data from the IMF.]

expenditure-output ratio equals roughly 0.78. The export-output ratio is roughly 0.32. The unemployment rate is marginally above 8%, and the average duration of unemployment  $1/\phi(x_0)$  is 0.7 years (8.4 months) (e. g., in 2007, in the OECD average unemployment duration was 8.8 months).<sup>21</sup> Welfare was calculated by computing the welfare integral (2), when the economy is in the corresponding steady state. In general, welfare is

$$W = \frac{1}{\epsilon} \int_0^{\infty} c(t)^\epsilon (1 - l(t) - s(t))^{\theta\epsilon} e^{-\beta t} dt \quad (15)$$

which in steady-state equilibrium simplifies to

$$\tilde{W} = \frac{1}{\epsilon} \frac{\tilde{c}^\epsilon (1 - \tilde{l} - \tilde{s})^{\theta\epsilon}}{\beta} \quad (16)$$

where steady-state values are denoted with a tilde.

Subsequent changes in welfare resulting from shocks and policies are obtained by expressing the change in the welfare measure (15) in terms of equivalent variations in the permanent flow of consumption necessary to equate the initial levels of welfare to what they would be following the shock and policies, both in the short run and in the long run.<sup>22</sup> Finally, we report the stable (negative) eigenvalues, which together contain information relevant to the speed of convergence, which at any point in time is a weighted average of the two stable eigenvalues. Over time, the weight of the smaller eigenvalue  $\mu_1$  declines, and the larger eigenvalue  $\mu_2$  describes the asymptotic speed of adjustment.<sup>23</sup> Note that  $\mu_1$  is large in absolute value, implying that the labor market adjusts relatively quickly, as we will see.

The four panels of Table 2 yield some interesting features of the steady-state equilibrium. Note that the benchmark is denoted in bold. First, the weight of the domestic good in consumption,  $\kappa$ , does not affect economic key variables other than the export-output ratio and the eigenvalues. The lower  $\kappa$  and thus the higher the weight of imports and the export-GDP ratio, the larger the eigenvalues in absolute value, and the economy converges more rapidly. Thus, the higher the degree of the economy's openness (expressed in the export-GDP ratio), the faster the economy adjusts to shocks.

Second, as the elasticity of substitution  $\sigma$  between the productive factors capital and labor increases, the capital-output ratio and production unsurprisingly increase, whereas the consumption-output and export-output ratios remain virtually unaffected. The more flexible the production structure, the less agents have to work and to search for jobs, and the equilibrium unemployment rate falls. The labor market adjusts more quickly as the elasticity of substitution increases, whereas the asymptotic speed of adjustment  $\mu_2$  is reduced.

Third, the steady-state depends on the economy's status as a creditor or debtor. As the economy reduces its net foreign assets and switches from a creditor to a debtor, production, labor and search as well as the export-GDP ratio increase, whereas the consumption-output ratio falls. The reason is the reduction in net

<sup>21</sup>Data were obtained online from the OECD Statistics Portal, url: <http://www.oecd.org/statsportal/>.

<sup>22</sup>We apply the method shown in the appendix of Alvarez-Cuadrado, Monteiro, and Turnovsky (2004). Initial welfare means the welfare at instant time zero and refers to the utility function, whereas overall (long-run) welfare refers to intertemporal welfare as given by the welfare integral (15).

<sup>23</sup>For further discussion on this point see Eicher and Turnovsky (1999, 2001).

Table 2: Base equilibrium

	$y_0$	$l_0$	$s_0$	$U(\%)$	$1/\phi(x_0)$	$(qk/y)_0$	$(Pc/y)_0$	$W_0$	$(Z/y)_0$ $\kappa = 0.2$	$(Z/y)_0$ $\kappa = 0.5$	$(Z/y)_0$ $\kappa = 0.8$	$\mu_1, \mu_2$ $\kappa = 0.2$	$\mu_1, \mu_2$ $\kappa = 0.5$	$\mu_1, \mu_2$ $\kappa = 0.8$
$\sigma = 0.5$														
$n_0 = 0.1$	0.382	0.339	0.0307	8.30	0.72	2.152	0.791	-263.36	0.517	0.319	0.121	-1.6470	-1.4708	-1.1987
$(n/y)_0 = 0.262$												-0.0778	-0.0745	-0.0671
$n_0 = 0$	0.386	0.342	0.0309	8.30	0.72	2.152	0.780	-267.30	0.520	0.325	0.130	-1.6463	-1.4739	-1.2098
$(n/y)_0 = 0$												-0.0780	-0.0747	-0.0676
$n_0 = -0.1$	0.389	0.345	0.0312	8.30	0.72	2.152	0.770	-271.31	0.524	0.331	0.139	-1.6454	-1.4769	-1.2206
$(n/y)_0 = -0.257$												-0.0782	-0.0750	-0.0681
$\sigma = 1$														
$n_0 = 0.1$	0.425	0.316	0.0276	8.02	0.70	2.894	0.788	-212.66	0.516	0.319	0.122	-1.6658	-1.4961	-1.2334
$(n/y)_0 = 0.235$												-0.0497	-0.0473	-0.0419
$n_0 = 0$	<b>0.428</b>	<b>0.319</b>	<b>0.0278</b>	<b>8.02</b>	<b>0.70</b>	<b>2.894</b>	<b>0.778</b>	<b>-215.34</b>	0.519	<b>0.324</b>	0.13	-1.6655	<b>-1.4987</b>	-1.2421
$(n/y)_0 = 0$												-0.0498	<b>-0.0474</b>	-0.0422
$n_0 = -0.1$	0.432	0.321	0.0280	8.02	0.70	2.894	0.769	-218.08	0.522	0.330	0.133	-1.6653	-1.5013	-1.2506
$(n/y)_0 = -0.232$												-0.0498	-0.0475	-0.0424
$\sigma = 1.25$														
$n_0 = 0.1$	0.456	0.301	0.0256	7.84	0.68	3.356	0.785	-184.94	0.515	0.318	0.122	-1.7094	-1.5397	-1.2793
$(n/y)_0 = 0.219$												-0.0404	-0.0382	-0.0334
$n_0 = 0$	0.460	0.303	0.0258	7.84	0.68	3.356	0.776	-187.03	0.518	0.323	0.129	-1.7091	-1.5421	-1.2873
$(n/y)_0 = 0$												-0.0404	-0.0382	-0.0336
$n_0 = -0.1$	0.463	0.305	0.0260	7.84	0.68	3.356	0.768	-189.15	0.520	0.328	0.137	-1.7087	-1.5444	-1.2951
$(n/y)_0 = -0.216$												-0.0405	-0.0383	-0.0337

Values other than the export output ratio  $(Z/y)_0$  and the roots  $\mu_1, \mu_2$  do not depend on  $\kappa$ .

interest earnings from abroad (which become payments in the debtor case), requires more production and higher exports, and more efforts to find a job in an attempt to keep consumption as high as possible along with absolute reductions in consumption to satisfy the intertemporal budget constraint. With more labor and search and less consumption, welfare falls.

### 3.3. Adjustments to a Negative Export Shock

Starting off from the initial equilibrium, we shall assume that world demand for domestic goods (exports) drops by 30%, i.e.  $Z_0$  is permanently scaled down by the factor 0.7. Table 3 summarizes the short-run and long-run percentage changes in unemployment, output, labor, net foreign assets, the relative price, consumption, and welfare following the shock as both net foreign assets  $n$  and  $\kappa$  vary, whereas the production function is given by the benchmark Cobb-Douglas technology (the tilde refers to the steady-state). The short-run change measures the impact effect that occurs when the export shock hits the economy. The long-run changes describe the steady-state responses, while the long-run welfare change measures the accumulated change in well being, as evaluated by the intertemporal utility function (15), as the economy traverses its transitional path. The results for the benchmark economy are set in bold.

As one can see from the second panel in table 3, in the benchmark case of a fairly export dependent economy (export-GDP ratio  $\approx 30\%$ ) with a Cobb-Douglas production technology and a initial zero NFA position ( $\sigma = 1$ ,  $\kappa = 0.5$  and  $n_0 = 0$ ), the export shock does not have any effects on unemployment, production, and the long-run NFA position. The reason for this result is simple. As the export drop hits the economy, the resulting excess supply on the domestic goods market causes an immediate increase in the real exchange rate,  $p$ , of about 8.75% to maintain goods market equilibrium. In turn, the depreciated real exchange rate reduces the purchasing power of the agent's income. The resulting negative income effect induces the agent to immediately reduce consumption expenditures  $c$  by roughly 4%. Interestingly, the labor market is not affected. Agents and firms do not change their search and hiring behavior, and unemployment remains thus constant. The reason is that households consumption expenditure  $Pc$  does not change, implying that their reservation wage does not change. As the supply side is not affected from the export shock, the bargained wage does not change either. Hence, households have no incentive to change their search behavior. Therefore, no labor dynamics emerge, and the economy is immediately in its new steady state. Because of the drop in consumption, the agent's welfare falls by roughly 4%. Thus, the only effect of the export drop is a once-and-for-all real depreciation to maintain goods market equilibrium, and a permanent reduction in consumption and the corresponding welfare loss. The result that the export shock has no effects on GDP is the same as in the Mundell-Fleming model. The flexible (real) exchange rate isolates the economy from foreign income shocks.<sup>24</sup>

Things change if the economy initially is a creditor or a debtor country. Panels 1 and 3 in table 3 report

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<sup>24</sup>However, the adjustment mechanism is different. Whereas in the Mundell-Fleming framework the real exchange rate has to depreciate to maintain balance of payments equilibrium, in our setup the real exchange rate has to depreciate to clear the domestic goods market.

Table 3: Changes in key variables upon export shock

	$\Delta s(0)\%$	$\Delta \tilde{y}\%$	$\Delta \tilde{l}\%$	$\Delta \tilde{n}\%$	$\Delta p(0)\%$	$\Delta c(0)\%$	$\Delta \tilde{c}\%$	$\Delta W(0)\%$	$\Delta \tilde{W}\%$
					$\sigma = 1$	$n_0 = 0.1$			
$\kappa = 0.2$	-0.930	-0.084	-0.084	1.324	9.099	-6.614	-6.621	-6.578	-6.581
$\kappa = 0.5$	-0.806	-0.080	-0.080	1.238	8.738	-3.972	-3.989	-3.939	-3.947
$\kappa = 0.8$	-0.651	-0.074	-0.074	0.951	8.316	-1.465	-1.503	-1.438	-1.457
					$\sigma = 1$	$n_0 = 0$			
$\kappa = 0.2$	0	0	0	0	9.085	-6.692	-6.692	-6.692	-6.692
$\kappa = 0.5$	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>8.749</b>	<b>-4.065</b>	<b>-4.065</b>	<b>-4.065</b>	<b>-4.065</b>
$\kappa = 0.8$	0	0	0	0	8.441	-1.582	-1.582	-1.582	-1.582
					$\sigma = 1$	$n_0 = -0.1$			
$\kappa = 0.2$	0.926	0.083	0.083	1.333	9.072	-6.769	-6.762	-6.806	-6.803
$\kappa = 0.5$	0.811	0.080	0.080	1.261	8.759	-4.157	-4.140	-4.191	-4.183
$\kappa = 0.8$	0.681	0.077	0.077	1.032	8.548	-1.698	-1.660	-1.727	-1.708

A tilde denotes steady-state. Benchmark set in bold.

the export shock's effects in case of a creditor ( $n_0 = 0.1$ ) and a debtor ( $n_0 = -0.1$ ) economy.<sup>25</sup> In these cases, the shock initiates transitional dynamics, and the Mundell-Fleming result of an isolating flexible exchange rate does not longer hold. The reason for this is that the depreciated real exchange rate, necessary to clear the domestic goods market, affects the value of the economy's net foreign assets and thus net interest income, expressed in terms of the domestic good. If the economy is a creditor, the value of foreign credit and interest income in terms of the domestic good increases, exercising a positive wealth effect which runs counter to the negative income effect of the exchange rate depreciation. Hence, on impact the agent reduces consumption expenditures by a somewhat smaller amount (3.97% instead of 4.065%). Because of the positive wealth effect, agents can afford to work less. They reduce search, leading to a short-run 0.8% fall in unemployment. Less search in turn implies that less jobs are matched, and employment begins to fall marginally. Lower employment in turn reduces the marginal product of capital, and firms will therefore gradually reduce their capital stock. In the long run, output, capital and employment all fall by the same, albeit very small amount (0.08%). During transition, the economy runs a current account surplus, and accumulates net foreign assets, which end up to be roughly 1.25% higher than before the shock. Finally, because the short- and long-run consumption reductions are a little bit moderated compared to the benchmark scenario, the short-run and long-run welfare losses are a little bit smaller.

In case of a debtor country, the effects of the export shock reverse. The value of outstanding debt and interest payments, expressed in terms of the domestic good, increase, giving rise to a negative wealth effect, which enforces the negative income effect of the real exchange rate depreciation. Hence, agents have

<sup>25</sup>Because the effects of the export shock on economic key variables other than the real exchange rate, consumption and welfare are quite small, we abstain from graphically reproducing the time paths.

to work more, which induces them to search more intensively for jobs, resulting in a short-run increase in unemployment by 0.81%. As time passes, more jobs are created and filled, and employment increases whereas unemployment falls. In the long run, output, capital and employment all rise by the same amount (0.08%). The increased capital stock is financed with additional debt, as the economy runs a current account deficit. It ends up with a 1.26% higher stock of (net) debt. Because the income effect and the wealth effect of the depreciation run in the same direction, the short- and long-run welfare losses are higher than in the benchmark economy.

Table 3 also reports the results of sensitivity analysis with respect to the export-GDP ratio (that is, by varying  $\kappa$ ). We can identify  $\kappa = 0.2, 0.5, 0.8$  as a very open, an open and a relatively closed economy in terms of export dependence.<sup>26</sup> The analysis confirms the commonsense perception that the more export dependent an economy is, the more it is affected by an export shock. In a very open economy (export-GDP ratio roughly 50%), the long-run welfare loss of the shock is close to 7%, whereas in a relatively closed economy (export-GDP ratio roughly 13%) it can be as small as roughly 1.5%. The reason is simple. The larger the share of exports in GDP, the more the shock reduces aggregate demand, and thus the larger is the resulting real depreciation, which in turn increases the income and wealth effects.

We also performed sensitivity analysis with respect to the flexibility in production,  $\sigma$ , and found that the elasticity of substitution in production does not have any significant effect on the economy's adjustments to the shock (not shown in table 3). This is intuitively plausible, as the shock impinges only on the economy's demand side, whereas the output response to the shock is very small.

#### 3.4. Adjustment to a Negative TFP Shock

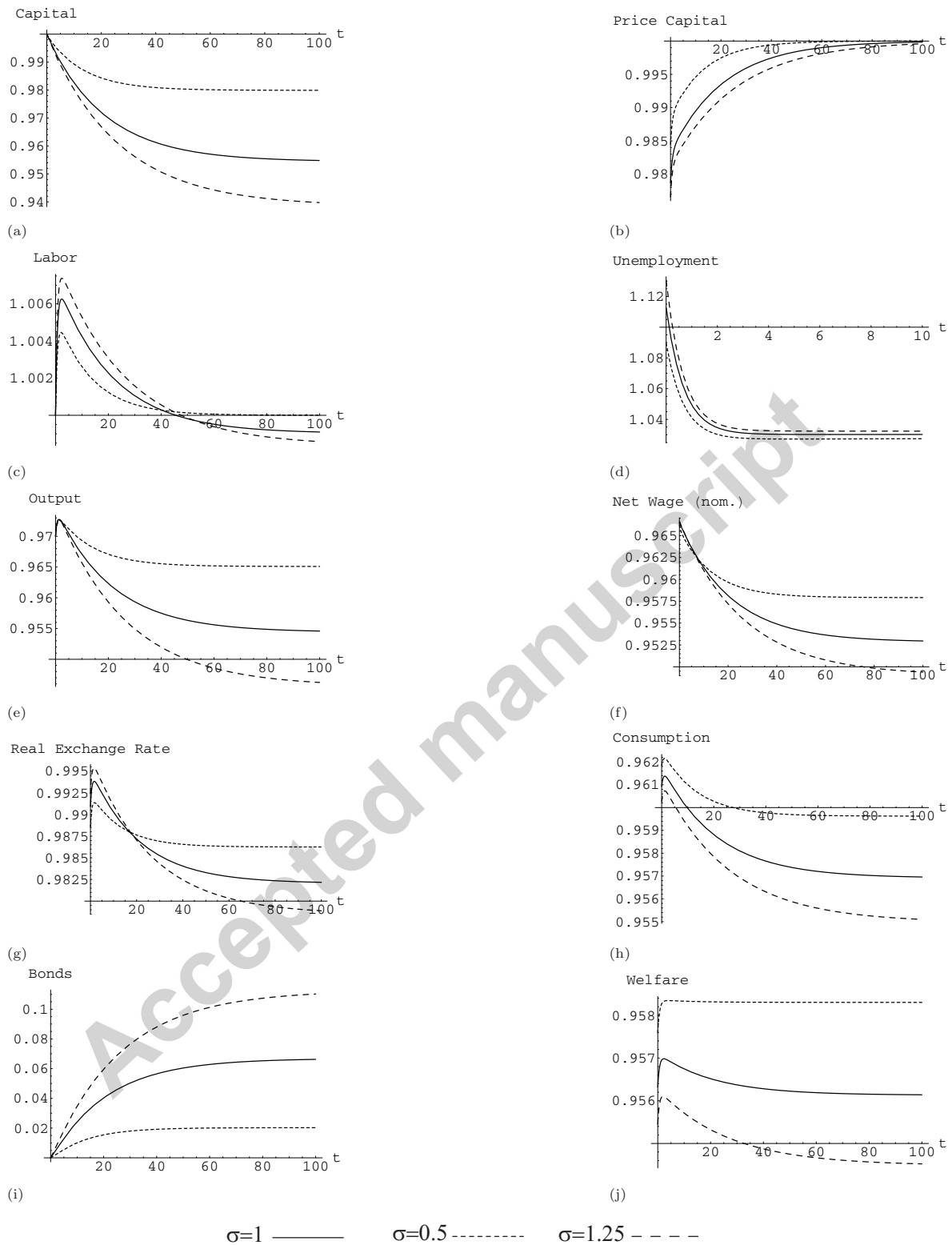
We now turn to the consequences of the “credit crunch”, caused by the financial crisis. The reluctance of banks supplying producers with credit causes a severe disruption and acts as “sand in the wheels” of production processes, as firms may run into troubles to finance purchases of inputs. As stressed in the introduction, we use total factor productivity as a proxy for the efficiency of financial intermediation and assume that total factor productivity of domestic production permanently declines by 3%, reducing  $A$  from 1 to 0.97.

##### 3.4.1. Short-Run and Long-Run Reactions

Figure 1 illustrates the time paths of economic key variables due to the TFP shock, as well as their sensitivity to variations in the elasticity of substitution,  $\sigma$ . The figure is based on the benchmark with  $\kappa = 0.5$  and  $n_0 = 0$ . Table 4 summarizes the short-run and long-run changes in unemployment, output, labor, the real exchange rate, consumption, and welfare following the shock as both  $\sigma$  and  $\kappa$  vary. For the benchmark Cobb-Douglas specification ( $\sigma = 1$  and  $\kappa = 0.5$ ) we also report the corresponding reactions for

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<sup>26</sup>The corresponding export-GDP ratios for the benchmark scenario  $\sigma = 1$  and  $n_0 = 0$  follow from Table 2 as 0.519, 0.324 and 0.13.

Figure 1: TFP Shock – Sensitivity analysis w.r.t.  $\sigma$

different levels of NFA. In contrast to the export shock, regardless of the economy's initial state the shock initiates transitional dynamics.

From figure 1, one can identify several qualitative types of transitional adjustment paths. First, consumption and instantaneous welfare complete the major part of their respective adjustments with an initial drop on impact. Second, capital declines gradually because adjustment costs prevent a discrete change. Third, employment, constrained to adjust continuously, too, barely changes during transition. Fourth, unemployment sharply increases on impact, but approaches its higher steady-state level relatively quickly; after three years the main part of adjustment is done. Fifth, wages fall on impact and continue to decline during the subsequent transition. Sixth, after their initial responses, employment, output, consumption, the real exchange rate and welfare increase during the very first stage of transition and then decline. Finally, bonds are accumulated during transition, as the economy runs a current account surplus, and the price of capital, after its initial drop, fully reverts to its pre-shock level.

Table 4: Changes in key variables upon negative TFP shock

	$\Delta s(0)\%$	$\Delta \bar{s}\%$	$\Delta \bar{y}\%$	$\Delta \bar{l}\%$	$\Delta p(0)\%$	$\Delta c(0)\%$	$\Delta \bar{c}\%$	$\Delta W(0)\%$	$\Delta \bar{W}\%$
					$\sigma = 0.5$	$n_0 = 0$			
$\kappa = 0.2$	9.744	2.792	-3.495	-0.005	-1.163	-3.449	-3.656	-3.913	-3.820
$\kappa = 0.5$	8.959	2.797	-3.491	0	-1.142	-3.817	-4.016	-4.241	-4.170
$\kappa = 0.8$	7.484	2.829	-3.460	0.031	-1.109	-4.169	-4.377	-4.523	-4.522
					$\sigma = 1$	$n_0 = 0$			
$\kappa = 0.2$	12.455	3.022	-4.577	-0.116	-1.007	-3.567	-3.876	-4.078	-3.990
$\kappa = 0.5$	<b>11.283</b>	<b>3.041</b>	<b>-4.559</b>	<b>-0.097</b>	<b>-0.907</b>	<b>-3.907</b>	<b>-4.288</b>	<b>-4.368</b>	<b>-4.344</b>
$\kappa = 0.8$	8.951	3.151	-4.457	0.009	-0.658	-4.163	-4.750	-4.528	-4.681
					$\sigma = 1.25$	$n_0 = 0$			
$\kappa = 0.2$	14.530	3.199	-5.472	-0.196	-0.908	-3.653	-4.030	-4.191	-4.109
$\kappa = 0.5$	13.025	3.233	-5.441	-0.164	-0.758	-3.974	-4.484	-4.455	-4.462
$\kappa = 0.8$	9.982	3.421	-5.268	0.018	-0.383	-4.169	-5.031	-4.537	-4.784
					$\sigma = 1$	$\kappa = 0.5$			
$n_0 = 0.1$	11.013	3.017	-4.582	-0.121	-0.907	-3.877	-4.261	-4.321	-4.302
$n_0 = 0$	<b>11.283</b>	<b>3.041</b>	<b>-4.559</b>	<b>-0.097</b>	<b>-0.907</b>	<b>-3.907</b>	<b>-4.288</b>	<b>-4.368</b>	<b>-4.344</b>
$n_0 = -0.1$	11.551	3.066	-4.536	-0.073	-0.908	-3.938	-4.315	-4.415	-4.386

A tilde denotes steady-state. Benchmark set in bold.

In the benchmark scenario, on impact the 3% TFP decline reduces output and marginal productivities by 3%. In turn, the market price of capital drops by roughly 2%, leading to investment expenditure cuts. The shock's negative wealth effect induces households to cut back consumption by roughly 4% and to reduce their reservation wage. Together with the lower marginal product of labor (-3%), bargained wages fall by more than 3%. As the reduction in output is larger than in aggregate demand, goods market equilibrium is restored by a lower, appreciated real exchange rate,  $p$ , causing exports  $Z$  to drop. The lower relative price,

$p$ , induces households to substitute away from the foreign good,  $c_f$ , to the domestic good. The reduction in imports  $c_f$  outweighs the drop in the value of exports  $Z/p$ , turning the current account into surplus. In an attempt to maintain a high consumption level via stabilizing income, households increase their search for jobs, raising thus unemployment by roughly 11% on impact. Higher search and lower consumption result in an instantaneous welfare loss of 4.37%.

In the very first stage of transition, because the wage drop is larger than the reduction in the marginal product of labor, firms find it profitable to employ more labor, which in turn raises output, calling for an increasing relative price to maintain goods market clearance. But as one can see from panels c, e, and g in figure 1, these effects are very small and short-living. Soon, the declining capital stock reduces labor productivity, and employment and output fall. Households recognize that on average their increased search for jobs is not successful. They become discouraged and reduce their search efforts, causing unemployment to fall quickly.

Over time, lower employment and capital cause ongoing reductions in output, and a falling capital intensity in production raises the marginal product of capital and thus  $q$ , slowing down capital decumulation as well as output and consumption reductions. Eventually, the economy reaches its new steady state, characterized by lower capital and output (roughly -4.5%), lower consumption (roughly -4.4%) and permanently higher unemployment (+3%), whereas employment has only fallen marginally. The overall welfare loss due to the TFP shock and the successive economic transition is roughly 4.3%.

### 3.4.2. Sensitivity Analysis

The first four panels of table 4 also report the results of some sensitivity analysis with respect to the elasticity of substitution in production,  $\sigma$ , and the degree of openness, proxied by  $\kappa$ , whereas the fifth panel contains sensitivity analysis with respect to the NFA position. Figure 1 shows how the dynamics depend on  $\sigma$ . The following observations can be made.

First, the lower the elasticity of substitution in production, the smaller the negative effects of the shock. The reason for this is that the TFP shock impinges on the production side. The less flexible the production process, the more important is the capital stock as an input, and the smaller therefore its reduction and the corresponding output loss. For example, for  $\sigma = 0.5$ , the long-run output loss is approximately 3.5%, whereas for  $\sigma = 1.25$  it is roughly 5.5%. Less output/income variation in turn implies smaller consumption changes, which reduce the incentives to search for a job, scaling therefore considerably down the unemployment impact response (from 13% to roughly 9%).

Second, the degree of openness of the economy does not have significant effects on variables other than short run unemployment, consumption, the real exchange rate, and welfare, which are the key variables of the household. Beside the income change, the main link between the shock and the demand side is the real exchange rate. The higher the economy's openness (the smaller  $\kappa$ ) and the larger therefore the share of imports in the agent's consumption bundle, the more consumers are affected from relative prices changes. Because the real exchange rate falls, higher import shares increase the (positive) income effect of the price

reduction, and agents can afford to cut back consumption by a smaller amount. The short-run and long-run welfare losses become therefore smaller. On the other hand, the higher the import share in consumption, the less search is affected from variations in  $p$ . Thus, the search-increasing effect of a higher job value  $\gamma$  plays a larger role, as the search-reducing effect of a lower relative price is scaled down. Hence, the more open the economy, the more households search on impact, which raises the short-run unemployment response.

Third, as the last panel in table 4 reveals, the effects of the TFP shock are barely sensitive to the economy's net foreign asset position. The lower the NFA position, the lower is net interest income, requiring households to cut back consumption more severely to meet their intertemporal budget constraint; hence, the greater are the responses of unemployment, consumption and welfare and the smaller are the reactions in output and labor.

We also performed sensitivity analysis with respect to the matching function parameter  $\chi$  and the worker's wage bargaining power,  $\varrho$ . Increasing  $\chi$  from 0.4 to 0.6 has almost no effects in the short run, whereas in the long run it results in higher unemployment and lower output, consumption, and welfare. Increasing worker's bargaining power  $\varrho$  from 0.4 to 0.6 shows that the higher  $\varrho$ , the smaller the short-run unemployment reaction, whereas all other economic variables are barely sensitive. Intuitively, the higher workers' bargaining power, the smaller the real wage reduction and thus the less sensitive search (unemployment) becomes.

Comparing the TFP shock with the export shock, two interesting findings should be noted. First, regardless of the degree of openness and the production flexibility, the TFP shock affects output, capital, unemployment and the economy's NFA position much more than the export shock. Second, depending on the type of shock, the economy's degree of openness affects the welfare loss differently. Whereas a higher degree of openness enlarges the welfare loss in case of an export shock, in case of a TFP shock the welfare loss becomes smaller.

### 3.4.3. Unemployment Dynamics

Unemployment dynamics merit further explanation. Search unemployment is determined by equation (4), i. e.  $s = s(l, \bar{\lambda}, p, \gamma, \phi)$ . One influential variable determining search is the value of a job,  $\gamma$ , which is given by equation (5). It is a forward-looking variable and represents the discounted present value of the future flow of the net real wage, expressed in terms of the foreign good,  $(1 - \tau_w)w/p$ , multiplied by the marginal utility of wealth,  $\bar{\lambda}$ . Figure 2 contains the time paths for the net real wage, expressed in terms of utility ( $\bar{\lambda}(1 - \tau_w)w/p$ ), and the value of a job, for the benchmark scenario ( $\sigma = 1, n_0 = 0, \kappa = 0.5$ ), and relative to their respective initial base levels. Panel 2(a) shows that on impact the net real wage expressed in terms of utility (and thus the value of working) jumps upward by roughly 8%, caused by the increase in  $\bar{\lambda}$ , and then falls rapidly within the first three years. This is due to the fact that during this period, the real wage drops sharply, as the nominal wage  $w$  falls, whereas the price  $p$  increases. Thereafter,  $p$  reverses its movement and falls, which heavily dampens the ongoing decline of the real wage. During the first three years, the evolution of the value of a job, depicted in panel 2(b), mirrors that of the net wage. On impact,  $\gamma$  jumps upwards by roughly 10% because of the increased time profile of the net real wage. The quick fall in the real wage leads to a reduction



Figure 2: Real wage and value of job

of  $\gamma$ , too. After three years or so, when the real wage stopped its quick downward movement, the value of a job stops falling and increases moderately thereafter, as the discount rate  $\zeta + \beta + \phi(t)$  becomes smaller (because the job finding rate  $\phi$  falls). As search is partially driven by the value of a job, see equation (4), in the first three years of transition search unemployment closely follows the time path of  $\gamma$ , as can be seen by comparing the graphs for  $\gamma$  and search (figure 1(d)). After three years, when  $\gamma$  reverses its adjustment, the rising  $\gamma$  is counterbalanced by ongoing reductions of the real exchange rate,  $p$ , and of the job finding rate,  $\phi$ , which both induce lower search. Hence, search unemployment remains stable, albeit at a permanently higher level (roughly +3%), because the steady-state value of a job is higher. Unemployment shows thus hysteresis.

### 3.5. Effects of a combined negative TFP and export shock

In the case of the financial crisis, many countries were hit in two ways: Their exports dropped due to the world recession, and the “credit crunch” spilled over to their financial markets, impinging negatively on TFP. To analyze the effects of this combined shock, we assume again that (i) exports drop by 30%, and that (ii) TFP falls by 3%. We restrict our attention on the benchmark economy. The first panel in table 5 reports the changes for both shocks, as they occur separately, as well as for the combined shock in the benchmark economy ( $\sigma = 1, \kappa = 0.5, n_0 = 0$ ). As one sees, the effects of the combined shock on unemployment, output, labor and the NFA position (absolute change) are almost the same as in case of a pure TFP shock. This is not surprising, as the export shock – viewed in isolation – has no effects on these variables. However, the consumption and welfare responses increase substantially if both shocks hit the economy at once. Their responses are almost as large as the sum of their reactions if one considers both shocks separately. The welfare loss almost doubles to roughly 8.25%. The real exchange rate plays a much more prominent role in absorbing the export demand shock than in accommodating the TFP supply shock, because the demand shock we assumed (aggregate demand drops by roughly 9%)<sup>27</sup> is much larger than the supply shock (on impact output falls by 3%), and goods market clearance requires the relative price to rise by roughly 8%.

The export shock is responsible for the direction of the exchange rate’s impact response, causing income and substitution effects, impinging negatively on consumption, whereas the TFP shock and its associated

<sup>27</sup>Exports drop by 30%. Assuming a share of exports in GDP of roughly 30%, aggregate demand falls by roughly 9%.

Table 5: Changes in key variables upon combined shock

	$\Delta s(0)\%$	$\Delta \bar{s}\%$	$\Delta \bar{y}\%$	$\Delta \bar{i}\%$	$\Delta p(0)\%$	$\Delta c(0)\%$	$\Delta \bar{c}\%$	$\Delta W(0)\%$	$\Delta \bar{W}\%$
export shock	0	0	0	0	8.749	-4.065	-4.065	-4.065	-4.065
TFP shock	11.283	3.041	-4.559	-0.097	-0.907	-3.907	-4.288	-4.368	-4.344
combined shock	11.226	3.042	-4.557	-0.096	7.768	-7.824	-8.193	-8.263	-8.243
$\kappa = 0.2$	12.435	3.022	-4.576	-0.116	7.988	-10.028	-10.318	-10.503	-10.423
$\kappa = \mathbf{0.5}$	<b>11.226</b>	<b>3.042</b>	<b>-4.557</b>	<b>-0.096</b>	<b>7.768</b>	<b>-7.824</b>	<b>-8.193</b>	<b>-8.263</b>	<b>-8.243</b>
$\kappa = 0.8$	8.878	3.156	-4.452	0.014	7.738	-5.683	-6.629	-6.039	-6.196

A tilde denotes steady-state. Benchmark set in bold.

permanently lower output exercises a negative wealth effect, reducing consumption and welfare further. The impact drop of consumption almost doubles. The time paths (not shown) of capital, output, labor, unemployment, and the real exchange rate as well as the economic interpretation of the adjustments are qualitatively the same as in case of a pure TFP shock (because we start off from a zero NFA position).

We also conducted sensitivity analysis with respect to production flexibility and the NFA position (not reported due to space restrictions), showing that the sensitivity of adjustments to the combined shock resembles that to a pure TFP shock. Regardless of the economy's NFA position, during transition a current account surplus emerges. The second panel in table 5 reports the results of sensitivity analysis with respect to the degree of openness in the benchmark economy. As one can see, the more open the economy (the smaller  $\kappa$ ), the more severe are the effects of the combined shock (only the change in long-run unemployment becomes marginally smaller). Whereas the adjustments to a pure export shock (see table 3), calling for a real exchange rate depreciation, are the more pronounced the higher the export dependence, the negative effects of a pure TFP shock, demanding an appreciation of the relative price, are mitigated as the export share increases. But in contrast to the export shock, the adjustments to a TFP shock are not very sensitive to the export share. The larger the export share in GDP, the more the real exchange rate has to depreciate on impact. Hence, the consumption and wealth effects increase with the degree of openness. The short-run unemployment response increases with openness, too, as a higher export and import shares scale up the income effect of the relative price change and thus the incentive to search for a job.

We can summarize that the export shock mainly exercises negative effects on the economy's demand side and leads to lower consumption, leaving the production side and thus the dynamic evolution of the economy almost unaffected, whereas the TFP shock as a supply side shock impinges both on output and aggregate demand, causing substantial transitional dynamics. The welfare effect of the export shock is the more pronounced the higher the economy's degree of openness and hence its exposition to foreign income disturbances, whereas production conditions rarely matter. In contrast, the welfare loss due to the TFP shock is the larger the less export dependent the economy is and the higher its production flexibility. Unemployment dynamics are mainly driven by the TFP shock. The impact on unemployment is the larger the higher the

economy's degree of openness and production flexibility.

#### 4. Conclusions

In this paper we have analyzed the impacts of TFP and export shocks on the economic performance of an open economy. The analysis is based on the well-known semi-small open economy model of the Turnovsky and Sen (1991) type. The key feature of the economy is that the labor market is non-Walrasian and suffers from frictions. Unemployment emerges as matching of job vacancies with searching agents is time-consuming and costly. Because of the model's complex dynamic structure, we resorted to numerical simulations, enabling us to analyze the short-run dynamics and the steady-state adjustments. We calibrated the model to replicate some structural key characteristics of OECD countries.

Attention has been focused on the extent to which the impacts of TFP and export shocks are sensitive to structural characteristics such as the economy's flexibility in production, its degree of openness, measured in terms of the export-GDP ratio, and its net foreign asset position. We show that the lower the elasticity of substitution in production, the less adverse are the effects on the economy. On the other hand, the higher the degree of integration into the world economy in terms of the export-GDP ratio, the more severe are the effects of the shock. The higher the country's net foreign asset position, the less pronounced are the welfare effects of the crisis. We also find that unemployment increases sharply on impact and reverts relatively quickly towards a permanently higher steady-state level, showing thus hysteresis. The export shock mainly causes a sharp real depreciation, along with a consumption and welfare loss, it shows little effect on output and unemployment. The TFP shock leads to substantial output and unemployment dynamics, but requires only a moderate appreciation of the real exchange rate. If both shocks hit the economy at once, the effects on output and unemployment resemble those of a pure TFP shock, whereas consumption and welfare losses almost double. Thus, the two shocks do not reinforce themselves

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## Glossary

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$A$	total factor productivity (TFP) parameter
$a$	government debt
$B$	scale parameter matching function
$b$	internationally traded bonds
$c$	consumption bundle
$c_d$	consumption domestic good
$c_f$	consumption foreign good
$g$	government expenditure on domestic good
$h$	investment adjustment cost parameter
$I$	gross investment
$k$	capital
$L$	leisure
$l$	labor ( $l^d$ labor demand, $l^s$ labor supply)
$M$	matching function
$m$	cost of vacancy
$n$	net foreign assets (NFA)
$P$	price consumption bundle
$p$	real exchange rate/relative price
$q$	price installed capital
$r$	world interest rate
$r_d$	domestic interest rate
$s$	search (unemployment)
$T$	lump-sum tax
$U$	instantaneous utility
$V$	value of firm
$v$	vacancy
$W$	welfare
$w$	wage rate
$x$	vacancy-unemployment ratio
$y$	output
$Z$	exports
$\alpha$	share of capital in production
$\beta$	rate of time preference
$\gamma$	value of job (worker)
$\delta$	depreciation rate of capital
$1/(1 - \epsilon)$	intertemporal elasticity of substitution
$\epsilon$	price elasticity exports
$\zeta$	job separation rate
$\theta$	elasticity of leisure in utility
$\kappa$	weight domestic good in consumption bundle
$\lambda$	marginal utility of wealth
$\mu_i$	eigenvalue $i$
$\xi$	shadow value labor (firm)
$\pi$	firm's after tax profit
$\varrho$	workers bargaining power
$\sigma \equiv 1/(1 + \rho)$	constant elasticity of substitution (production)
$\tau_c$	consumption tax rate
$\tau_k$	capital income tax rate
$\tau_w$	labor tax rate
$\phi$	job finding rate
$1/\phi$	average duration unemployment
$\varphi$	vacancy filling rate
$\chi$	weight of vacancies in matching function
$\psi$	intra-temporal elasticity of substitution between $c_d$ and $c_f$
tilde	steady-state value

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