Annex C

A Dynamic General Equilibrium model to analyse the effects of Seine flooding

To evaluate the macroeconomic impact of a flood in the Paris region, a dynamic general equilibrium model, including both private and public capital, was developed and calibrated to the French economy. Flooding is modelled as a shock, destroying parts of capital stocks and reducing business turnover.

Model setup

Representative household

The representative household derives utility from consuming and having leisure. Consistent with balanced growth, their preferences are given by $\log(C_t) + \nu \log(1 - N_t)$. They discount the future using a factor β. Taking as given interest rates (r^g on government debt and r^p on private debt), wages (w), taxes (τ) and firms' profits (Π), which are distributed as a lump-sum to the households owning the firm, the representative household decides how much to consume (C) and work (N) as well as how much to save in government bonds (S^g) and private corporate bonds (S^p). They solve the following maximisation programme:

$$\max_{\{C_t, N_t, S_t^g, S_t^p\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t (\log(C_t) + \nu \log(1 - N_t))$$

$$s.t.\, C_t + S_t^g + S_t^p = (1-\tau_t)(w_t N_t + \Pi_t + (1 + r_{t-1}^g) S_{t-1}^g + (1 + r_{t-1}^p) S_{t-1}^p$$

which has the following first-order conditions:

$$1-N_t = \frac{\nu C_t}{(1-\tau_t) w_t} \qquad (1)$$

$$\frac{1}{C_t} = \beta(1+r_t^g)(1-\tau_{t+1}) \frac{1}{C_{t+1}} \qquad (2)$$

$$\frac{1}{C_t} = \beta(1+r_t^p)(1-\tau_{t+1}) \frac{1}{C_{t+1}} \qquad (3)$$

$$C_t + S_t^g + S_t^p = (1-\tau_t)(w_t N_t + \Pi_t + (1+r_{t-1}^g) S_{t-1}^g + (1+r_{t-1}^p) S_{t-1}^p) \qquad (4)$$

Equation (1) is the intratemporal condition for the optimal mix of consumption and leisure. Equations (2) and (3) are intertemporal optimality conditions relating future to current consumption; for both government and corporate bonds to be traded in equilibrium, they require $r_t^g = r_t^p = r_t$. Then the household is indifferent between the two bonds and is only concerned about the total amount of savings $S_t = S_t^g + S_t^p$. The household optimality conditions in this case become:

$$1 - N_t = \frac{vC_t}{(1-\tau_t)w_t} \tag{5}$$

$$\frac{1}{C_t} = \beta(1+r_t)(1-\tau_{t+1})\frac{1}{C_{t+1}} \tag{6}$$

$$C_t + S_t = (1-\tau_t)(w_t N_t + \Pi_t + (1+r_{t-1})S_{t-1}) \tag{7}$$

Representative firm

Following Baxter and King's (1993) seminal work, we assume that output (Y) is produced using public capital (X), private capital (K) and labour (N) according to a Cobb-Douglas technology that exhibits constant returns to scale in the private inputs, private capital and labour:

$$Y_t = A_t X_{t-1}^{\Theta} K_{t-1}^{\alpha} N_t^{1-\alpha} \tag{8}$$

where A_t is a productivity parameter. The subscripts on the public and private capital stock are $t-1$ since in period t only capital that has been build up previously can be utilised for production. Both types of capital depreciate each period at a rate δ.

The representative firm maximises an infinite stream of cash flows, using the households' discount factor Q_t (since the households' are the shareholders). They take interest rates and wages as given, and can borrow by issuing private corporate bonds (B^p) to invest in their capital stock ($I_t^p = K_t + (1-\delta)K_{t-1}$).[1] But as in Kiyotaki and Moore (1997), due to asymmetric information in the capital markets, they can only borrow against collateral, for which they can use up to fraction φ<1 of their capital stock. The borrowing constraint is therefore $B_t^p \leq \varphi K_t$.

A firm that has outstanding debt B_{t-1}^p and starts the period with existing capital stock $(1-\delta)K_{t-1}$ solves the following equation:

$$\max_{\{K_t, N_t, B_t^p\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} Q_t\left(A_t X_{t-1}^{\theta} K_{t-1}^{\alpha} N_t^{1-\alpha} - w_t N_t - K_t + (1-\delta)K_{t-1} + B_t^p - (1+r_{t-1})B_{t-1}^p\right)$$

$$s.t.\ B_t^p \leq \varphi K_t$$

Assuming that firms' borrowing constraints bind in all periods, and hence $B_t^g = \varphi K_t$ and $\mu_t > 0$, the firm's optimal behaviour is characterised by:

$$1-\varphi=\frac{Q_{t+1}}{Q_t}\left(\alpha A_t X_{t-1}^{\Theta} K_{t-1}^{\alpha-1} N_t^{1-\alpha}+1-\delta-\varphi(1+r_t)\right) \tag{9}$$

$$N_t=\left(\frac{(1-\alpha)A_t X_{t-1}^{\Theta} K_{t-1}^{\alpha}}{w_t}\right)^{\frac{1}{\alpha}} \tag{10}$$

where the first equation pins down the optimal investment into the next period's capital stock and the second equation's firms' labour demand. Notice that the first term in the parenthesis in the optimality condition for private investment (equation 9) is private capital's marginal product. It is increasing in public capital due to complementarities in production. Likewise, the optimality condition indicates that there are complementarities between both types of capital and labour.

Profits in period t, which flow back to the households, are:

$$\Pi_t=A_t X_{t-1}^{\Theta} K_{t-1}^{\alpha} N_t^{1-\alpha}-w_t N_t-(1-\varphi)K_t+(1-\delta-\varphi(1+r_{t-1}))K_{t-1} \tag{11}$$

Note that given preferences, in equilibrium the household's discount factor between periods t and t+1 is given by $\frac{Q_{t+1}}{Q_t}=\beta\frac{C_t}{C_{t+1}}\frac{1-\tau_{t+1}}{1-\tau_t}$, since the household is indifferent between receiving a dividend (before taxes) of 1 in period t or of $\frac{C_t}{C_{t+1}}\frac{1-\tau_{t+1}}{1-\tau_t}$ in t+1. Moreover, since taxes and consumption are constant in steady state, firm's are discounting their future profits with the household's discount factor β.[2]

Steady state conditional on government policies

The government invests in the public capital stock (X), levies income taxes (τ) and issues government bonds B^g. The government's budget constraint in period t is therefore given by:

$$B_t^g+\tau_t(w_t N_t+\Pi_t+(1+r_{t-1})S_{t-1})=(1+r_{t-1})B_{t-1}^g+X_t-(1-\delta)X_{t-1} \tag{12}$$

The market clearing condition for the bond market is:

$$S_t=B_t^g+B_t^p=B_t^g+\varphi K_t \tag{13}$$

The economy is summarised by equations (5, 6, 7, 9, 10, 11). In steady state, with constant policies all variables are constant, the government budget (12) and the behaviour of the household's and firm and are summarised by:

$$\tau(wN+\Pi+(1+r)S)=rB^g+\delta X \tag{14}$$

$$1-N=\frac{\nu C}{(1-\tau)w} \tag{15}$$

$$1+r=\frac{1}{\beta(1-\tau)} \quad (16)$$

$$C+S=(1-\tau)(wN+\Pi+(1+r)S) \quad (17)$$

$$1-\varphi=\beta\left(\alpha AX^{\Theta}K^{\alpha-1}N^{1-\alpha}+1-\delta-\varphi(1+r)\right) \quad (18)$$

$$N=\left(\frac{(1-\alpha)AX^{\Theta}K^{\alpha}}{w}\right)^{\frac{1}{\alpha}} \quad (19)$$

$$\Pi=AX^{\Theta}K^{\alpha}N^{1-\alpha}-wN-(\delta+\varphi r)K \quad (20)$$

$$S=B^{g}+\varphi K \quad (21)$$

As shown in Annex D, conditional on government policies, this system of equations can be solved for the steady state values of capital, consumption and employment, which yields:

$$K=\frac{\dfrac{(1-\alpha)\left(\alpha\beta AX^{\Theta}\right)^{\frac{1}{1-\alpha}}}{d^{\frac{\alpha}{1-\alpha}}}-\dfrac{\alpha\beta\nu}{1-\tau}(r-\tau-\tau r)B^{g}}{(1+\nu-\alpha)d-\alpha\beta\nu(\frac{\tau}{1-\tau}\varphi+\delta)} \quad (22)$$

$$C=\frac{(1-\tau)(1-\alpha)}{\nu\alpha\beta d^{\frac{\alpha}{1-\alpha}}}\frac{\left(\alpha\beta AX^{\Theta}\right)^{\frac{1}{1-\alpha}}(\nu d-\alpha\beta\nu(\frac{\tau}{1-\tau}\varphi+\delta))+d^{\frac{1}{1-\alpha}}\frac{\alpha\beta\nu}{1-\tau}(r-\tau-\tau r)B^{g}}{(1+\nu-\alpha)d-\alpha\beta\nu(\frac{\tau}{1-\tau}\varphi+\delta)} \quad (23)$$

$$N=\frac{(1-\alpha)d-d^{\frac{1}{1-\alpha}}\frac{\alpha\beta\nu}{1-\tau}(r-\tau-\tau r)B^{g}\left(\alpha\beta AX^{\Theta}\right)^{\frac{-1}{1-\alpha}}}{(1+\nu-\alpha)d-\alpha\beta\nu(\frac{\tau}{1-\tau}\varphi+\delta)} \quad (24)$$

Where:

$$d=\left(1-\varphi+\beta(\varphi(1+r)-1+\delta)\right)$$

Government

Public policies are chosen to maximise the welfare of the representative consumer, taking into account the effect of these policies on the economy, i.e. by taking into account how private firms and households react to policy changes.

A truly benevolent government's maximisation problem should be to choose $\{X_t, \tau_t, B_t^p\}_{t=0}^{\infty}$ in order to max (log(C_t)+νlog(1−N_t)) subject to the government's budget constraint (12) and equations (1) to (11), which describe the economy in each period. This optimisation problem, however, is not tractable.[3] Instead, it is assumed that the government solves:

$$\max_{\{X, \tau, B^g\}^{\infty}} (\log(C\quad) + \nu \log(1 - N\quad))$$

subject to the government's budget constraint (12) and equations (15) to (24), which describe the response of the economy if it was in a steady state in each period.[4]

As can be seen from equations (23) and (24), steady state consumption and employment depend on fiscal policies, i.e. $C(\tau,X,B^g)$ and $N(\tau,X,B^g)$. After substituting out the government budget constraint, the maximisation problem is to choose {X,τ} to $max(\log(C\quad) + \nu \log(1 - N\quad))$, and the first order conditions for X and τ are:

$$\frac{1}{C(X,\tau)}\frac{dC}{dX} = \frac{\nu}{1-N(X,\tau)}\frac{dN}{dX} \quad (25)$$

$$\frac{1}{C(X,\tau)}\frac{dC}{d\tau} = \frac{\nu}{1-N(X,\tau)}\frac{dN}{d\tau} \quad (26)$$

An expression for these first-order conditions is shown in Annex D.

Calibration

The model is calibrated to the French economy on a quarterly frequency. The year 2010 is treated as a steady state in the absence of a shock.

As standard in the literature, following Hansen (1985), the elasticity of output with respect to private capital is set to α=0.36. This value is also consistent with recent estimates for the production function in the euro area by Willman (2002). Commissioned by the French government, the Lebègue Report (Baumstark, 2005) suggests the use of an annual discount rate of 4%.

Since the model is at quarterly frequency, the model's discount factor is set to $\beta=\left(\frac{1}{1+0.04}\right)^{1/4}=0.9902$.

There is no consensus in the literature on the depreciation rate of capital,[5] but a wide range of estimates for developed economies, from around 4% (e.g. Hansen, 1985) to 15% or higher (e.g. Piketty, 2013) per year. As a baseline, the depreciation rate is therefore set to a mid-range value suggested by INSEE and referenced in Smets and Wouters (2007), implying at quarterly frequency δ=0.025.

Parameters, including the depreciation rate and the discount factor, are subject to sensitivity analysis to show how the model results change with these parameter values.

The remaining parameters are Θ, ν, and φ, which are chosen to match private capital, public capital and public finances of the French economy as of 2010.

The parameter Θ is the elasticity of output with respect to public capital. To the extent that public investment takes into account how it affects production and GDP, the observed public investment is informative about this parameter.

The parameter ν is a preference parameter capturing the households' disutility from working compared to utility from consumption. As capital and labour are complements in production, changes in employment also affect private capital. Hence the ratio of private capital to GDP in France is informative about this preference parameter of French households.

The last parameter, φ, describes how tight borrowing constraints are for French firms. As lenders can split their financial wealth between lending to firms or the government, but firms' ability to borrow is limited by this constraint, in equilibrium the part of savings that is not lent to firms will go to the government. Hence, the observed government fiscal position is also informative about parameter φ.

While these parameters are clearly calibrated jointly, intuitively Θ is chosen to match investment into public capital, φ to match taxes levied on production activities, and ν is chosen to replicate the private capital to output ratio (see equation 22).

From OECD.Stat Dataset: 9A. "Fixed assets by activity and by asset, ISIC rev4", the private and public capital stock in 2010 are calculated to be EUR 7 482 462.235 million and EUR 2 098 771.215 million (2010 prices).[6] From OECD.Stat Dataset: 14A. "Non-financial accounts by sectors" taxes on production activities are calculated to be 25.68% of GDP.

Table C.1 lists all model parameters and their calibrated values.

Table C.1. **Calibrated parameters**

	Parameter	Value	Source/target
α	Elasticity of output w.r.t private capital	0.36	Hansen (1985)
Θ	Elasticity of output w.r.t public capital	0.2311	To match X/Y=.5994
β	Households' discount factor	0.9902	Lebègue Report (2005)
ν	Preference for leisure	0.7735	To match K/Y=2.137
δ	Depreciation rate of capital	0.0250	Smets and Wouters (2007)
φ	Tightness of entrepreneurs' borrowing constraint	0.3828	τ=0.2569
A	Total factor productivity	1	Normalisation

Results

The economy is simulated, starting in steady state, and experiencing flooding at the beginning of the first quarter. The interest rate is taken exogenously (at its steady state level) to reflect the fact that within the euro area interest rates are equalised.

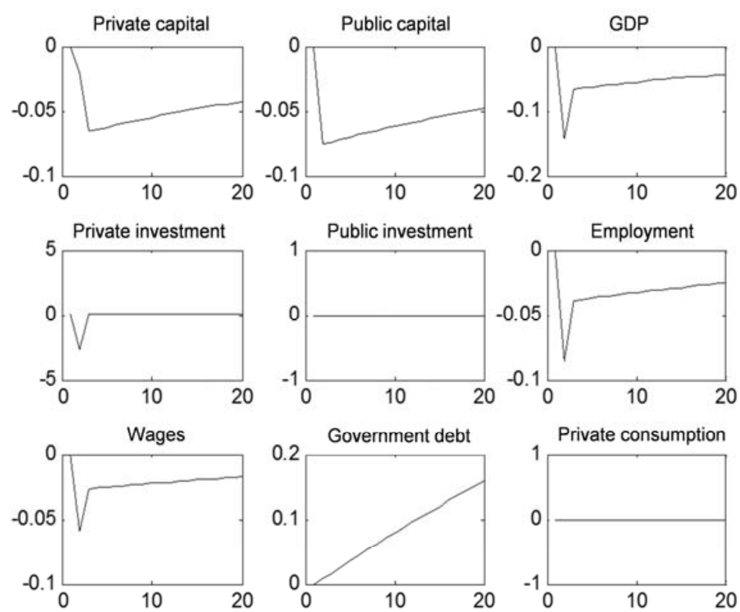
In the first set of simulations, as a benchmark, it is assumed that after the flooding there is no change in fiscal policies. Investment in public capital is therefore as in steady state given by δXss. Since after the shock Xt<Xss, this public investment is higher than break-even investment, i.e. the investment that would be needed to keep capital constant at its current value (δXt). As a consequence, even in the absence of a change in fiscal policies, public capital grows over time, albeit very slowly as there is no additional investment following the destruction caused by the flooding.

In the second set of simulations, it is assumed that public investment responds after the flooding, and as a consequence the economy recovers much quicker.

Results under constant fiscal policies

Figure C.1 shows for scenario 1 the evolution of key variables after the flooding if there was no change in fiscal policies. The graph shows how the variables differ in percentage terms to their initial value, i.e. the value before the flood shock disturbed the economy. The horizontal axis is time, measured in quarters. Period 0 is the economy's initial steady state in the absence of a shock. At the beginning of period 1, the flooding shock occurs; afterwards the economy converges gradually over time to a steady state. Since none of the shocks are permanent, the economy will eventually fully recover.

Figure C.1. **Scenario 1: Constant fiscal policies**



In period 1, when the shock hits, both a part of private and public capital is destroyed, and as a consequence, GDP drops immediately. Since capital and labour are complements in production, employment and wages also fall.[7] As the government's tax revenue falls along with the reduction in economic activity (the tax rate is in this simulation assumed to be constant) but its spending on investment in public capital remains unchanged (again assumed here), government debt rises.

On impact, quarterly GDP drops by 0.15% and employment by 0.09%. In subsequent periods, as more and more capital is rebuilt, the effects weaken and wages recover. Therefore, the substitution effect of lower wages weakens, leading to a rise in labour supply and employment during the recovery, which contributes to the recovery in GDP.

To simulate the different scenarios, shocks to private and public capital stocks are introduced that destroy a fraction (s^K,s^X) at the beginning of period 1. In addition, to model the turnover reduction, a shock to A is introduced (s^A). Based on an initial annual turnover of EUR 3 596.4 billion. Table C.2 shows the values of these shocks for the different scenarios.

Table C.2. **Calibration of shocks**

	S1	S2	S3A	S3B
Destruction of capital stock				
Destruction of private capital (EUR billions)	1.53	8.56	14.98	14.98
s^K	-0.020%	-0.114%	-0.200%	-0.200%
Destruction of public capital (EUR billions)	1.6	4.67	14.03	14.03
s^X	-0.110%	-0.230%	-0.573%	-0.573%
Turnover reduction				
Persistent due to SME bankruptcy: Year 1			1.25	3.00
Year 2			0.60	1.50
Year 3			0.30	0.70
Year 4			0.00	0.00
Temporary: Business interruption: Quarter 1	0.58	5.67	12.33	12.33
Quarter 2				2.69
Quarter 3				0.98
s^A in quarter 1	-0.065%	-0.631%	-1.406%	-1.455%
s^A in quarter 2	-0.065%	0.000%	-0.035%	-0.383%
s^A in quarter 3	0.000%	0.000%	-0.035%	-0.192%
s^A in quarter 4	0.000%	0.000%	-0.035%	-0.083%
s^A in quarters 5-8	0.000%	0.000%	-0.017%	-0.042%
s^A in quarters 9-12	0.000%	0.000%	-0.008%	-0.019%

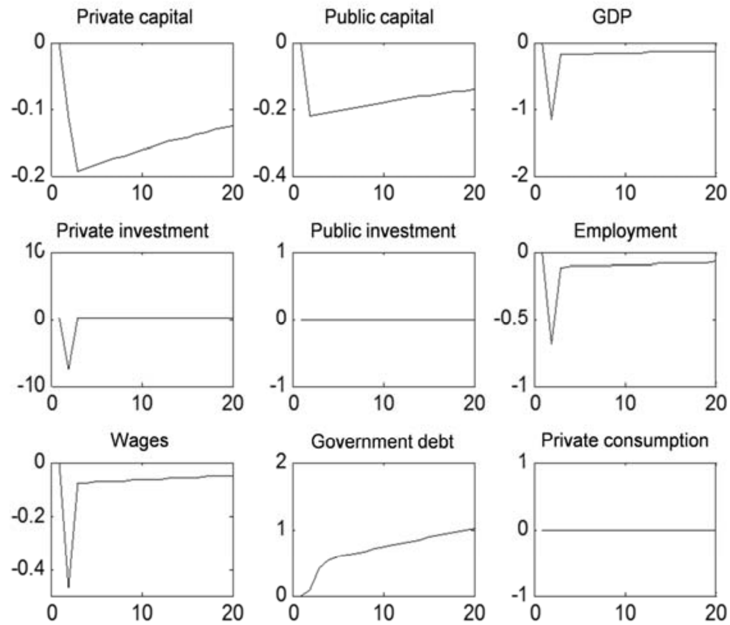
After the flooding, reserves on reconstruction are drawn up, which are introduced into the model as a transfer from the government to firms. Table C.3 summarises these payments, expressed relative to the initial quarterly GDP. Consistent with the CATNAT system's requirement of reimbursements no later than three months after the claim, it is assumed in the simulations that damages in quarter 1 will be reimbursed in quarters 2 (at 75%) and 3 (25%) and damages in quarter 2 will be reimbursed in quarters 3 (75%) and 4 (25%). These reimbursements might increase government debt after the reserves of EUR 5.7 billion are exhausted.

Table C.3. **Calibration of reconstruction reserves**

	S1	S2	S3A	S3B
Private capital	0.266%	1.634%	2.883%	2.883%
1st quarter turnover	0.019%	0.343%	0.667%	0.667%
2nd quarter turnover	0.000%	0.000%	0.000%	0.151%

Figure C.2 plots the transition of the economy when flood scenario 2 occurs in period 1, assuming no change in fiscal policies. Qualitatively, the response of the economy is very similar to scenario 1. However, since the shock is more severe, and more private and public capital is destroyed and the drop in business turnover is higher in the quarter of the flooding, GDP and employment fall by more than in scenario 1. In scenario 2, the contemporaneous reduction in quarterly GDP is 1.16% and in employment 0.69%.

Figure C.2. **Scenario 2: Constant fiscal policies**



In both variants of scenario 3 it is assumed that the flooding leads to a more persistent reduction of turnover due to the exit of some small and medium-sized enterprises. For this reason, the economy of scenario 3 will recover slower than in the previous scenarios. As in scenarios 1 and 2, when the shock hits, some private and public capital are destroyed, and therefore employment, wages, GDP, tax revenue and private consumption fall immediately. Because of the assumed more persistent reduction in business turnover, private investment and therefore production recover slowly. But also in this case, private consumption is unaffected as households can smooth the persistent, but nonetheless temporary, reduction in national income over their infinite planning horizon.

The difference between variant A and variant B of scenario 3 is in the magnitude and persistence of the additional reduction in business turnover. In variant A this additional reduction is much more short-lived than in variant B, and as a consequence private investment and the aggregate economy recover faster in variant A. Since capital and labour are complements in production, employment and wages follow the pattern of private capital and pick up later in variant 3B than in variant 3A. For the quarter in which the flooding occurs, the calibrated model predicts a drop in GDP by 2.62% in variant A and by 2.70% in variant B. Similarly, the contemporaneous fall in employment is predicted to be 1.57% in variant A and 1.62% in variant B.

Summary of the macroeconomic effects under constant policies

The calibrated dynamic general equilibrium model of the French macroeconomy predicts in all scenarios that the destruction of private and public capital along with the turnover reduction due to the flooding leads to an immediate reduction of GDP and employment in the quarter of the flooding, ranging from a drop of 0.15% in GDP and 0.09% in employment in the best case (scenario 1) to 2.7% for GDP and 1.6% for employment in the worst case (scenario 3B).

Figure C.3. **Scenario 3A: Constant fiscal policies**

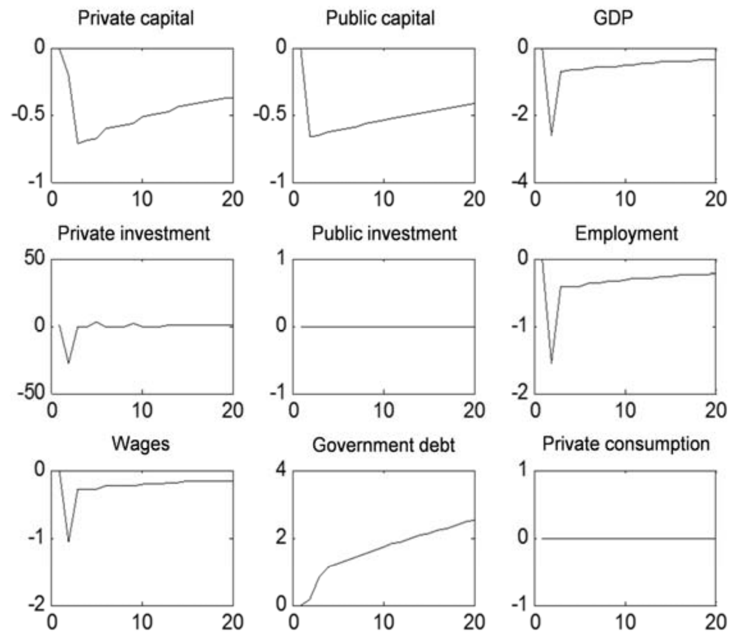
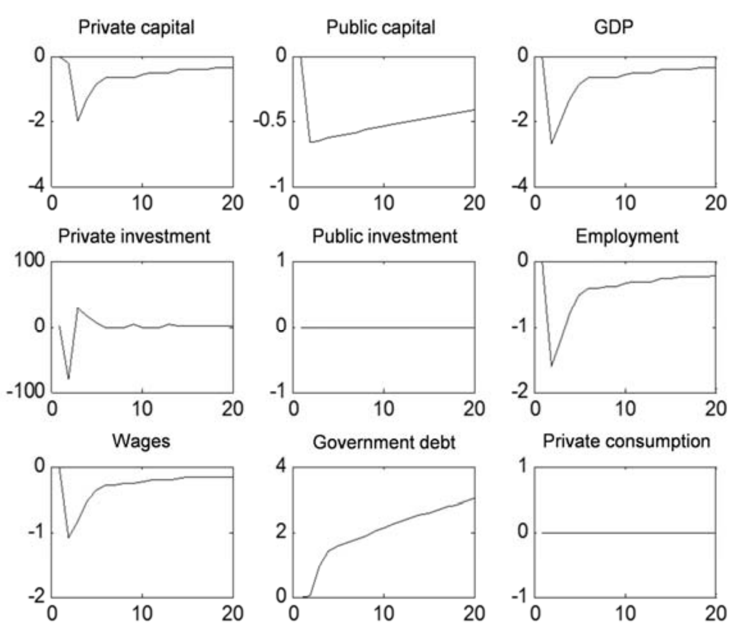


Figure C.4. **Scenario 3B: Constant fiscal policies**



Since the tax base falls with the reduction of economic activity, the model also predicts an immediate rise in government debt between 0.008% (scenario 1) and 0.16% (scenario 3). In subsequent quarters, government debt continues to rise, as reserves from the CATNAT system are drawn up to finance reconstruction and the tax base remains below its initial level, assuming no change in fiscal policies.

The speed of the recovery varies across the scenarios, with scenario 3 seeing a rather slow recovery due to the persistent reduction in business turnover caused by the exit of small and medium-sized enterprises.

Table C.4 summarises at a yearly frequency the consolidated effects over five years on the GDP, employment and government debt for the different scenarios. The effects on GDP and employment are shown as the yearly average percentage deviation to the value before the flooding; the effect on government debt is shown as the percentage increase in the stock of debt relative to its initial value.

Table C.4. **The consolidated effects under constant policies**

In percentage

Year	Scenario 1			Scenario 2			Scenario 3A			Scenario 3B		
	GDP	Empl	Gov debt	GDP	Empl	Gov debt	GDP	Empl	Gov debt	GDP	Empl	Gov debt
1	-0.084	-0.050	0.035	-0.432	-0.257	0.578	-1.180	-0.705	1.238	-1.729	-1.034	1.562
2	-0.059	-0.035	0.071	-0.172	-0.102	0.701	-0.582	-0.346	1.624	-0.678	-0.403	2.020
3	-0.053	-0.031	0.104	-0.156	-0.092	0.820	-0.498	-0.296	1.977	-0.540	-0.321	2.417
4	-0.048	-0.028	0.136	-0.141	-0.084	0.935	-0.422	-0.251	2.298	-0.422	-0.251	2.755
5	-0.043	-0.026	0.166	-0.127	-0.076	1.046	-0.381	-0.227	2.609	-0.381	-0.227	3.084

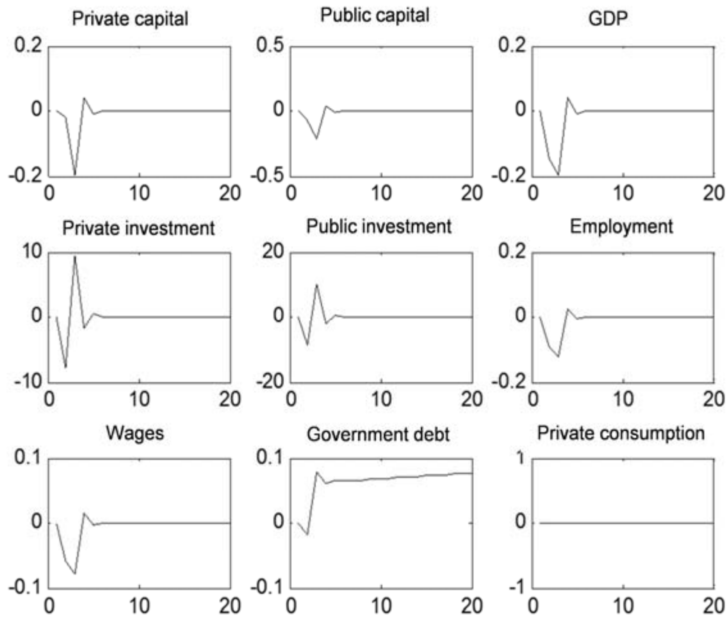
Results when public investment reacts to the shock

The previous section analysed the transition path of the economy assuming no change in fiscal policies. However, since not only the private sector is affected by the flooding, but part of the public capital is also destroyed, there might be a change in public investment following the shock. This section therefore analyses the transition path of the economy assuming that public investment is adjusted according to the optimality condition (25). Figures C.5 to C.8 show the response of the economy to the flooding taking into account how public investment is predicted to change.

Taking into account the change in public investment, Figure C.5 shows the response of the economy in scenario 1.

Upon impact, quarterly GDP and employment fall by 0.15% and 0.09%, which is about the same as in Figure C.1. However, in subsequent periods, the economy behaves differently. In the quarter following the flooding, public investment picks up in order to rebuild the capital stock quickly. As this increases the marginal product of private capital, private investment then increases by more than before. As a consequence, both capital stocks revert more quickly to their steady state values. Since labour is complementary to both, employment and wages also return to their steady state values more quickly. Government debt, however, rises more in the short run compared to the situation of constant fiscal policies. This is to finance the additional public investment that would allow the reconstruction of the public capital stock. In the long run, however, public debt rises in this case by less since the economy, and therefore tax revenue, recover faster.

Figure C.5. **Scenario 1: Assuming change in public investment**



Similarly for scenario 2, when public investment reacts to the flooding, quarterly GDP falls by 1.18% and employment by 0.72%, but compared to the case of constant fiscal policies, the recovery is much faster, as shown in Figure C.6.

In scenario 3, on impact GDP and employment fall by 2.66% and 1.63% in variant A, or 2.74% and 1.68% in variant B. In all scenarios, the policy response entails a cut of public investment during the period of shock, since during that period resources are scarce, turnover reduced and employment below its steady state level. In the quarter following the flooding, however, there is a large increase in public investment in order to restore public capital quickly. As a result, public capital as well as private capital, whose marginal productivity depends positively on public capital, recover fast. Since labour is complementary to both types of capital in production, the path of employment and wages qualitatively follow the same pattern of a faster recovery. While GDP returns much faster to its steady state level when public investment is adjusted according to equation (25), this policy change increases government debt at least in the short run, and in scenario 3B also in the long run.

Figure C.6. **Scenario 2: Assuming change in public investment**

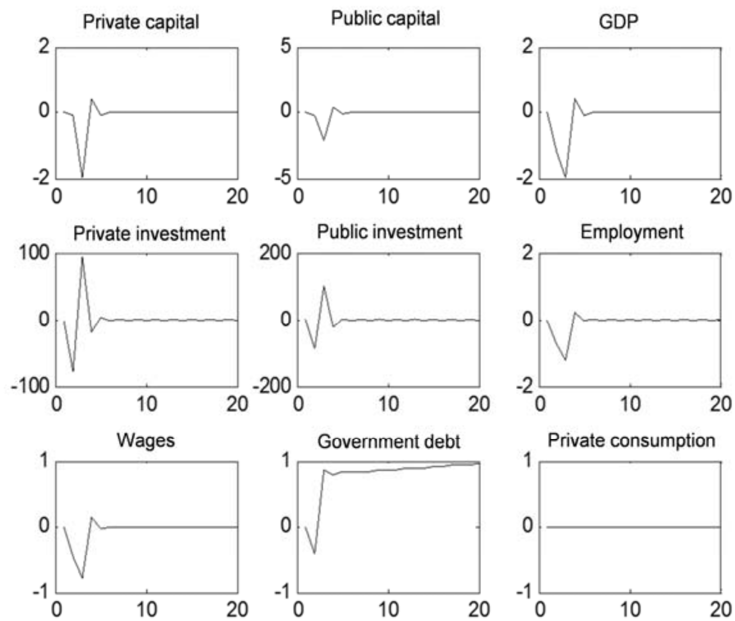


Figure C.7. **Scenario 3A: Assuming change in public investment**

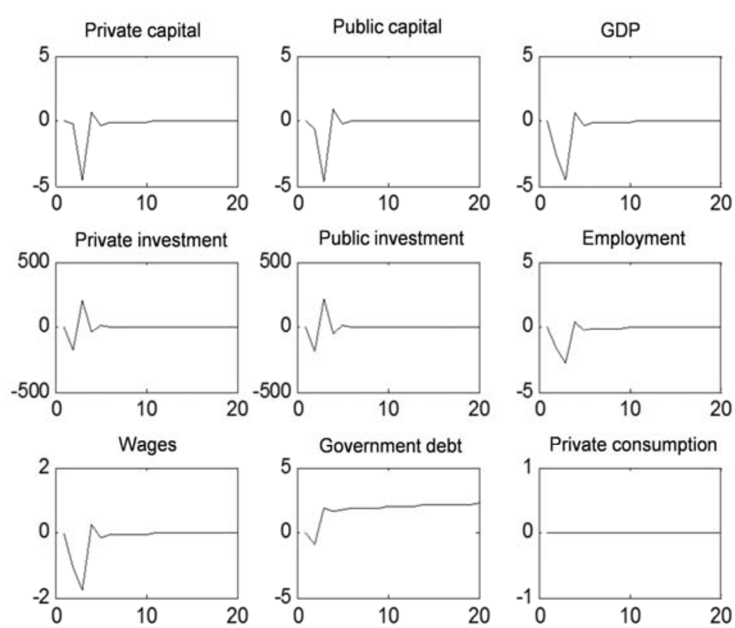
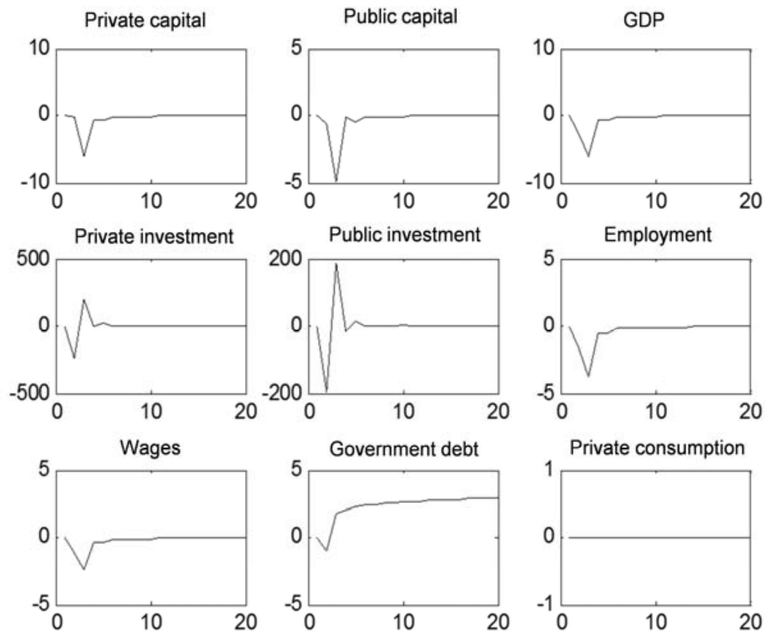


Figure C.8. **Scenario 3B: Assuming change in public investment**



Summary of the macroeconomic effects under optimal public investment

Table C.5 summarises at a yearly frequency the consolidated effects over five years on GDP, employment and government debt for the different scenarios when taking into account the response of public investment. As in Table C.4, the effects on GDP and employment are shown as the yearly average percentage deviation to the value before the flooding and the effect on government debt is shown as the percentage increase in the stock of debt relative to its initial value.

Table C.5. **The consolidated effects under optimal public investment**

In percentage

Year	Scenario 1			Scenario 2			Scenario 3A			Scenario 3B		
	GDP	Empl	Gov debt	GDP	Empl	Gov debt	GDP	Empl	Gov debt	GDP	Empl	Gov debt
1	-0.078	-0.047	0.065	-0.708	-0.433	0.824	-1.730	-1.066	1.803	-2.618	-1.614	2.280
2	0.000	0.000	0.068	0.003	0.002	0.852	-0.107	-0.065	1.941	-0.267	-0.162	2.539
3	0.000	0.000	0.071	0.000	0.000	0.888	-0.054	-0.033	2.060	-0.129	-0.078	2.737
4	0.000	0.000	0.074	0.000	0.000	0.925	-0.004	-0.002	2.152	-0.009	-0.005	2.866
5	0.000	0.000	0.077	0.000	0.000	0.964	0.000	0.000	2.240	0.000	0.000	2.983

Comparing Tables C.4 and C.5 shows that the adjustment in public investment alleviates effects on GDP and employment in subsequent years, but might increase the negative effects in the initial year, as the increase in government investment might crowd out private activity in the short run.

Contribution of each shock (in scenario 3A)

To disentangle the contribution of the three shocks, the economy is simulated, when flooding affects only private capital, public capital or business turnover. Table C.6 summarises the consolidated effects for scenario 3A when public investment responds to the shock.

Table C.6. **Counterfactual scenario 3A: If only one shock**

In percentage

Year	Only private capital			Only public capital			Only turnover		
	GDP	Empl	Gov debt	GDP	Empl	Gov debt	GDP	Empl	Gov debt
1	-0.024	-0.015	0.653	-0.052	-0.032	0.258	-1.66	-1.02	0.84
2	0.000	0.000	0.681	0.000	0.000	0.269	-0.11	-0.06	0.94
3	0.000	0.000	0.710	0.000	0.000	0.280	-0.05	-0.03	1.02
4	0.000	0.000	0.740	0.000	0.000	0.291	0.00	0.00	1.07
5	0.000	0.000	0.772	0.000	0.000	0.303	0.00	0.00	1.12

Comparing the columns of Table C.6 to each other[8] and to the baseline results for scenario 3A in Table C.5 highlights that the reduction in business turnover is by far the most important impact of the flooding on the economy.

Sensitivity analysis

To analyse how robust the numerical results are, a sensitivity analysis is conducted. For different sets of parameter values, the model with optimal public investment is simulated for scenarios 1 and 3A, the two most extreme scenarios. The alternative parameter values considered are for annual discount rate values of 4%, 7%, 10% or 13%, which imply for β at quarterly frequency 0.9902, 0.9832, 0.9765, 0.9699 and 0.9657 respectively. For the depreciation rate δ the alternative values at quarterly frequency are 0.01, 0.018, 0.026, 0.034 and 0.04. Table C.7 shows the implied consolidated effects for combinations of these alternative values.

Comparing Tables C.5 and C.7 shows that the results regarding GDP, employment and government debt are rather robust to these changes in parameter values. Other assumptions of the model are in the specification of preferences. The setup presented here uses log-log-utility in consumption and leisure. This implies an intertemporal elasticity of substitution of 1, which is in this study an innocent assumption, since the interest rate is assumed to be exogenous throughout. Hence, the household does not react to changes of the interest rate but attains steady state consumption in each period. The other elasticity implied by these preferences is a Frisch elasticity of labour supply of unity. The justification for using these preferences is that they are consistent with economic growth, in the sense that a change in an economy's per capita income does not change employment in the long run.

Summary

A dynamic general equilibrium model is utilised to evaluate the macroeconomic impact of flooding in the Paris region. Flooding is introduced into the model as a shock that destroys part of the private and public capital stock, as well as reducing business turnover. Fiscal policies are able to help with the subsequent recovery, but have no scope to alleviate the direct impact of the shock.

Table C.7. **Sensitivity analysis**

	Scenario 1			Scenario 3A		
Year	GDP	Empl	Gov debt	GDP	Empl	Gov debt
β=0.9902, δ=0.01						
1	-0.074	-0.042	0.048	-1.631	-0.937	1.660
2	0.001	0.000	0.048	-0.086	-0.048	1.751
3	0.000	0.000	0.051	-0.048	-0.027	1.850
4	0.000	0.000	0.053	-0.003	-0.002	1.932
5	0.000	0.000	0.056	0.000	0.000	2.010
β=0.9832, δ=0.018						
1	-0.079	-0.048	0.069	-1.750	-1.089	1.858
2	0.000	0.000	0.074	-0.109	-0.066	2.059
3	0.000	0.000	0.080	-0.055	-0.034	2.248
4	0.000	0.000	0.086	-0.004	-0.002	2.417
5	0.000	0.000	0.092	0.000	0.000	2.590
β=0.97645, δ=0.026						
1	-0.080	-0.050	0.074	-1.778	-1.124	1.894
2	0.000	0.000	0.082	-0.113	-0.071	2.165
3	0.000	0.000	0.091	-0.056	-0.035	2.431
4	0.000	0.000	0.100	-0.004	-0.002	2.688
5	0.000	0.000	0.111	0.000	0.000	2.963
β=0.9699, δ=0.034						
1	-0.081	-0.051	0.076	-1.788	-1.138	1.905
2	0.000	0.000	0.086	-0.116	-0.072	2.240
3	0.000	0.000	0.099	-0.057	-0.036	2.583
4	0.000	0.000	0.112	-0.004	-0.003	2.936
5	0.000	0.000	0.128	0.000	0.000	3.327
β=0.9657, δ=0.04						
1	-0.081	-0.051	0.077	-1.790	-1.141	1.904
2	0.000	0.000	0.089	-0.116	-0.073	2.280
3	0.000	0.000	0.103	-0.057	-0.036	2.676
4	0.000	0.000	0.120	-0.004	-0.003	3.097
5	0.000	0.000	0.139	0.000	0.000	3.571

Notes

1. Since the return on corporate and government bonds is the same, a firm does not have any incentive to borrow for saving in government debt.
2. This will also be true on the transition path, as it is assumed that taxes and the interest rate remain constant.
3. It is also not clear that in reality governments solve infinite horizon optimisation problems.
4. That is, the derivatives of the equations describing the decentralised equilibrium are taken using the steady state relationship, but evaluated using prices $\{\tau_t, w_t, r_t\}$ of each period.

5. These differences are mainly due to what goods are included in the classification of capital, e.g. durables.

6. Private capital includes fixed assets of the following activities: agriculture, forestry and fishing, mining and quarrying, manufacturing, construction, wholesale and retail trade, repair of motor vehicles and motorcycles, transport and storage (at 50%), accommodation and food service activities, financial and insurance activities, real estate activities, professional, scientific and technical activities; legal, accounting, management, architecture, engineering activities, scientific research and development; other professional, scientific and technical activities; administrative and support service activities, residential care and social work activities, arts, entertainment and recreation, other service activities, activities of households as employers as well as goods and services-producing activities of households for own use. All other fixed assets are classified as public capital.

7. Since also household wealth is reduced by the shock, private consumption also falls (and this income effect implies an increase of labour supply at constant wages). However, due to the constant interest rate, this drop in consumption goes to zero, as households spread the finite drop in household wealth over an infinite time horizon.

8. Most of the increase in government debt when there is only the shock to private capital is due to the state guarantee to reimburse the losses caused by the flooding – excluding these reimbursements, government debt would rise only by 0.04% in year 1 and 0.047% in year 5 if the only shock was to private capital.

References

Baxter, M. and R.G. King (1993), “Fiscal policy in general equilibrium”, *American Economic Review*, No. 8, pp. 315-334.

Baumstark, L. (2005), Lebègue Report

Hansen, G.D. (1985), “Indivisible labor and the business cycle”, *Journal of Monetary Economics*, Vol. 16, No. 3, pp. 309-327.

Kiyotaki, N. and J. Moore (1997), “Credit cycles”, *Journal of Political Economy*, Vol. 105, No. 2, pp. 211-248.

Lebègue, D. (2005), *Le prix du temps et la décision publique,* Commissariat Général du Plan, La documentation Française.

Piketty, T. (2013), *Le capital au 21e siècle*, Ed. du Seuil, Paris.

Smets, F. and R. Wouters (2007), “Shocks and frictions in US business cycles: A Bayesian DSGE approach”, *American Economic Review*, Vol. 97, No. 3, pp. 586-606.

Willman, A. (2002), “Euro area production function and potential output: A supply side system approach”, *Working Paper Series 0153*, European Central Bank.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