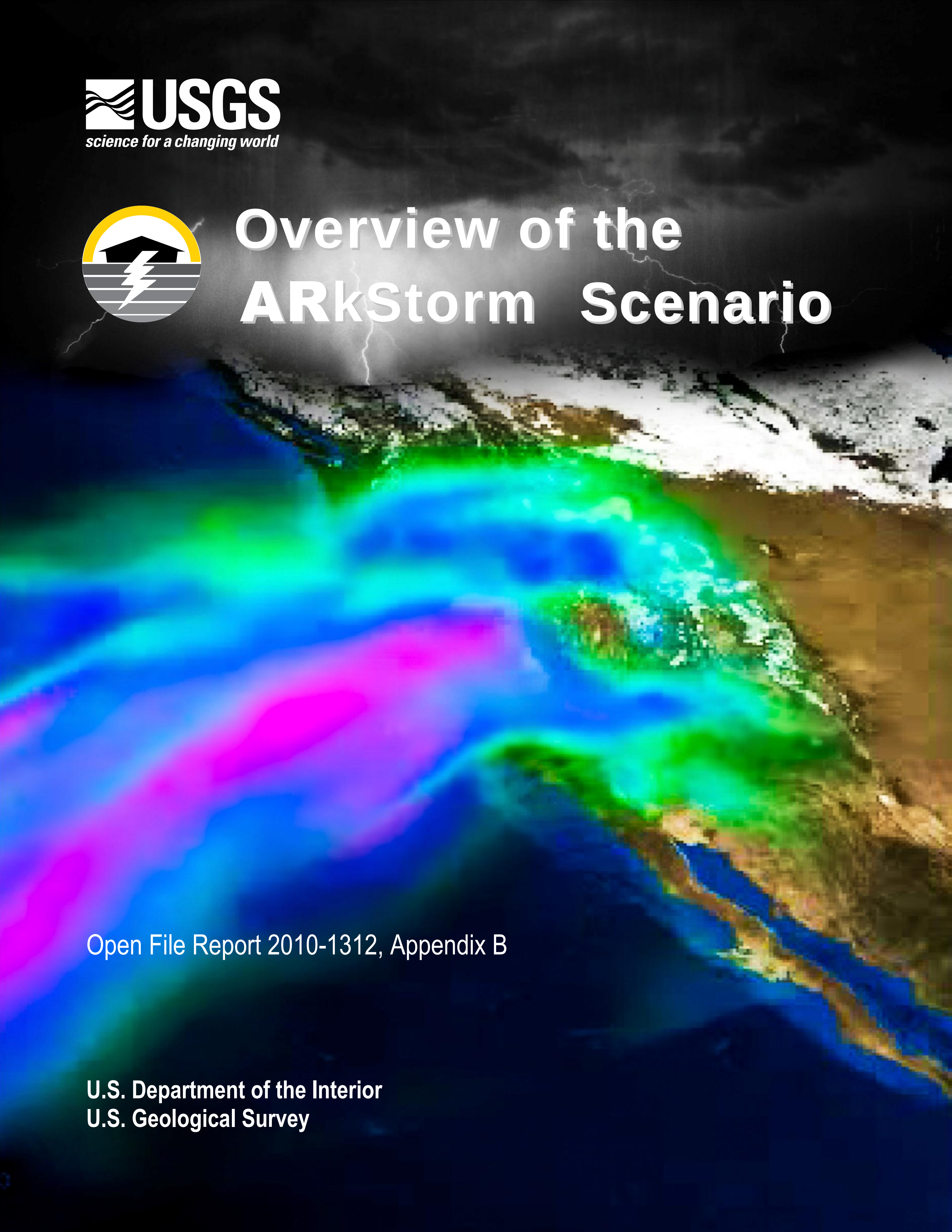

science for a changing world

Overview of the ARkStorm Scenario

Open File Report 2010-1312, Appendix B

U.S. Department of the Interior
U.S. Geological Survey

Model Appendix

1. Introduction

This appendix summarizes the design, construction and application of a recursive dynamic computable general equilibrium (CGE) simulation model of the California economy. The application is over a time horizon of ten semi-annual periods from the onset of a severe storm.

A CGE model is a stylized computational representation of the circular flow of the economy. It solves for the set of commodity and factor prices and activity levels of firms' outputs and households' incomes that equalize supply and demand across all markets in the economy (Sue Wing, 2009). The present model divides California's economy into 100 industry sectors, each of which is modeled as a representative firm characterized by a constant elasticity of substitution (CES) technology to produce a single good or service. Households are modeled as a representative agent with CES preferences and a constant marginal propensity to save and invest out of income. The government is also represented in a simplified fashion. Its role in the circular flow of the economy is passive: collecting taxes from industries and passing some of the resulting revenue to the households as a lump-sum transfer, in addition to purchasing commodities to create a composite government good which is consumed by the households. Three factors of production are represented within the model: labor, as well as intersectorally mobile and sector-specific varieties of capital, all of which are owned by the representative agent and rented out to the firms in exchange for factor income. California is modeled as an open economy which engages in trade with the rest of the U.S. and the rest of the world using the Armington specification (imports from other states and the rest of the world are imperfect substitutes for goods produced in the state).

The static component of the model computes the prices and quantities of goods and factors that equalize supply and demand in all markets in the economy, subject to constraints on the external balance of payments. This equilibrium sub-model is embedded within a dynamic process, which on a 6-month time-step specifies exogenous improvements in firms' productivity and updates the economy's capital endowments based on investment-driven accumulation of the stocks of capital. The impacts of a severe storm are modeled as exogenous shocks to the productivity of industries, reductions in household consumption and investment, and contemporaneous destruction of capital stock, with concomitant reductions in the economy's endowments of capital input.

2. Production

The supply side of the model employs a variant of the hierarchical nested CES production structure presented in Rose and others (2009). Output in sector j is produced by combining a composite of capital, energy and labor ($QKEL_j$, with price $PKLE_j$) with a composite of intermediate non-energy inputs (QM_j, with price PM_j):

$$PY_j = \Phi_{j,Y}\left[\alpha_{KEL,j}^{\sigma_{KELM,j}} PKLE_j^{1-\sigma_{KELM,j}} + \alpha_{M,j}^{\sigma_{KELM,j}} PM_j^{1-\sigma_{KELM,j}}\right]^{1/(1-\sigma_{KELM,j})}. \tag{1a}$$

where $\Phi_{j,Y}$ is a productivity parameter used to represent the effect of output losses associated with the storm. In turn, the capital-energy-labor composite is produced from an amalgam of capital and labor (QKL_j, with price PKL_j) and energy (QE_j, with price PE_j):

$$PKLE_j = \left[\alpha_{KL,j}^{\sigma_{KLE,j}} PKL_j^{1-\sigma_{KLE,j}} + \alpha_{E,j}^{\sigma_{KLE,j}} PE_j^{1-\sigma_{KLE,j}}\right]^{1/(1-\sigma_{KLE,j})}, \tag{1b}$$

while the capital-labor aggregate is produced from a capital composite (QK_j, with price PK_j) and labor (QL_j, with price PL_j):

$$PKL_j = \left[\alpha_{K,j}^{\sigma_{KL,j}} PK_j^{1-\sigma_{KL,j}} + \alpha_{L,j}^{\sigma_{KL,j}} PL_j^{1-\sigma_{KL,j}}\right]^{1/(1-\sigma_{KL,j})}, \tag{1c}$$

and the capital composite combines intersectorally mobile and sector-specific capital (QKS_j and QKM_j, with prices PKS_j and PKM_j)

$$PK_j = \left[\alpha_{KM,j}^{\sigma_{KK,j}} PKM_j^{1-\sigma_{KK,j}} + \alpha_{KS,j}^{\sigma_{KK,j}} PKS_j^{1-\sigma_{KK,j}}\right]^{1/(1-\sigma_{KK,j})}. \tag{1d}$$

Energy is made up of electricity ($Q_{Elec,j}$, with price $P_{Elec,j}$) and a non-electric fuel composite ($QFUEL_j$, with price $PFUEL_j$):

$$PE_j = \left[\alpha_{ELE,j}^{\sigma_{E,j}} P_{Elec}^{1-\sigma_{E,j}} + \alpha_{FUEL,j}^{\sigma_{E,j}} PFUEL_j^{1-\sigma_{E,j}}\right]^{1/(1-\sigma_{E,j})} \tag{1e}$$

in which the latter is a CES aggregation of intermediate inputs of fuel commodities ($q_{i,j}$, with price P_i, $i \in \mathcal{F}$):

$$PFUEL_j = \left[\sum_{i\in\mathcal{F}} \alpha_{i,j}^{\sigma_{FUEL,j}} P_i^{1-\sigma_{FUEL,j}}\right]^{1/(1-\sigma_{FUEL,j})}. \tag{1f}$$

Turning to intermediate non-energy inputs, the materials composite is produced by combining a composite of services ($QSRV_j$, with price $PSRV_j$), a composite of transport ($QTRN_j$, with price $PTRN_j$) and an amalgam of other intermediate goods and services ($QNST_j$, with price $PNST_j$):

$$PM_j = \begin{bmatrix} \alpha_{SRV,j}^{\sigma_{M,j}} PSRV_j^{1-\sigma_{M,j}} + \alpha_{TRN,j}^{\sigma_{M,j}} PTRN_j^{1-\sigma_{M,j}} \\ +\alpha_{OM,j}^{\sigma_{M,j}} PNST_j^{1-\sigma_{M,j}} \end{bmatrix}^{1/(1-\sigma_{M,j})}. \tag{1g}$$

In turn, services are made up of a composite of financial services (QFS_j, with price PFS_j) and an amalgam of other services (QOS_j, with price POS_j):

$$PSRV_j = \left[\alpha_{FS,j}^{\sigma_{SRV,j}} PFS_j^{1-\sigma_{SRV,j}} + \alpha_{OS,j}^{\sigma_{SRV,j}} POS_j^{1-\sigma_{SRV,j}}\right]^{1/(1-\sigma_{SRV,j})}, \tag{1h}$$

the transport aggregate combines a composite of truck, rail, air, and water transportation (QTR_j, with price POT_j) with an amalgam of other transport services (QOT_j, with price POT_j):

$$PTRN_j = \left[\alpha_{TR,j}^{\sigma_{TRN,j}} PTR_j^{1-\sigma_{TRN,j}} + \alpha_{OT,j}^{\sigma_{TRN,j}} POT_j^{1-\sigma_{TRN,j}}\right]^{1/(1-\sigma_{TRN,j})}, \tag{1i}$$

and the aggregate of other materials is comprised of a composite of chemicals (QCM_j, with price PCM_j) and an amalgam of other intermediates (QOM_j, with price POM_j):

$$PNST_j = \left[\alpha_{CM,j}^{\sigma_{NST,j}} PCM_j^{1-\sigma_{NST,j}} + \alpha_{OM,j}^{\sigma_{NST,j}} POM_j^{1-\sigma_{NST,j}}\right]^{1/(1-\sigma_{NST,j})}. \tag{1j}$$

Finally, each of the sub-aggregates is itself an amalgam of intermediate use of commodities ($q_{i,j}$, with prices P_i), grouped according to Table 1:

$$PFS_j = \left[\sum_{i\in\mathcal{FS}} \alpha_{i,j}^{\sigma_{FS,j}} P_i^{1-\sigma_{FS,j}}\right]^{1/(1-\sigma_{FS,j})}. \tag{1k}$$

$$POS_j = \left[\sum_{i\in\mathcal{OS}} \alpha_{i,j}^{\sigma_{OS,j}} P_i^{1-\sigma_{OS,j}}\right]^{1/(1-\sigma_{OS,j})}. \tag{1l}$$

$$PTR_j = \left[\sum_{i\in\mathcal{TR}} \alpha_{i,j}^{\sigma_{TR,j}} P_i^{1-\sigma_{TR,j}}\right]^{1/(1-\sigma_{TR,j})}. \tag{1m}$$

$$POT_j = \left[\sum_{i\in\mathcal{OT}} \alpha_{i,j}^{\sigma_{OT,j}} P_i^{1-\sigma_{OT,j}}\right]^{1/(1-\sigma_{OT,j})}. \tag{1n}$$

$$PCM_j = \left[\sum_{i\in\mathcal{CM}} \alpha_{i,j}^{\sigma_{CM,j}} P_i^{1-\sigma_{CM,j}}\right]^{1/(1-\sigma_{CM,j})}. \tag{1o}$$

$$POM_j = \left[\sum_{i\in\mathcal{OM}} \alpha_{i,j}^{\sigma_{OM,j}} P_i^{1-\sigma_{OM,j}}\right]^{1/(1-\sigma_{OM,j})}. \tag{1p}$$

3. Trade and Commodity Supply

Trade is modeled according to the standard Armington specification, in which each sector's output supplies domestic and export markets, and the aggregate supply of each good is an aggregate of domestic and imported varieties. Looking first at exports, producers in each sector allocate their output to supply in-state and out-of-state markets, represented by the outputs QYD_j and QYX_j with prices PYD_j and PYX_j, respectively. Out-of-state supplies are further allocated among goods destined for the rest of the U.S. ($QXUS_j$, with price $PRUS_j$) and those shipped to other countries (QXO_j, at the generalized price of foreign exchange PFX). The device used to model the optimal allocation decision is the constant elasticity of transformation (CET) function. Using $PYT_j = \left(1+\tau_j^Y\right)PY_j$ to represent the gross-of-tax price of sector j's output (where τ_j^Y denotes the benchmark tax rate on production and imports), output transformation is specified as

$$PYT_j = \left[\beta_{YD,j}^{\eta_{XD,j}} PYD_j^{1-\eta_{XD,j}} + \beta_{YX,j}^{\eta_{XD,j}} PYX_j^{1-\eta_{XD,j}}\right]^{1/(1-\eta_{XD,j})}, \tag{2a}$$

while the allocation of exports is given by:

$$PYX_j = \left[\beta_{XRUS,j}^{\eta_{XX,j}} PRUS_j^{1-\eta_{XX,j}} + \beta_{XF,j}^{\eta_{XX,j}} PFX^{1-\eta_{XX,j}}\right]^{1/(1-\eta_{XX,j})}. \quad (2b)$$

Imports of the i^{th} commodity (QYM_i, with price PYM_i) are modeled as a CES composite of quantities of that good emanating from US and international sources ($QMUS_i$ and QMO_i, with prices $PRUS_i$ and PFX, respectively):

$$PYM_i = \left[\beta_{MRUS,i}^{\sigma_{MM,i}} PRUS_i^{1-\sigma_{MM,i}} + \beta_{MF,i}^{\sigma_{MM,i}} PFX^{1-\sigma_{MM,i}}\right]^{1/(1-\sigma_{MM,i})}. \quad (2c)$$

Finally, imported and domestic varieties of each commodity are aggregated together to yield the supply Q_i of an Armington composite good at consumer price P_i:

$$P_i = \left[\beta_{MD,i}^{\sigma_{MD,i}} PYD_i^{1-\sigma_{MD,i}} + \beta_{MF,i}^{\sigma_{MD,i}} PYM_i^{1-\sigma_{MD,i}}\right]^{1/(1-\sigma_{MD,i})}. \quad (2d)$$

We adopt a simple trade closure for the model. By Shephard's lemma, the market clearance conditions for sectoral output and the domestic variety of the j^{th} good are:

$$QY_j = \frac{\partial PYT_j}{\partial PYD_j} QY_j + \frac{\partial PYT_j}{\partial PYX_j} QY_j, \quad (2e)$$

$$\frac{\partial PYT_j}{\partial PYD_j} QY_j = \frac{\partial P_j}{\partial PYD_j} Q_j. \quad (2f)$$

We assume that California is a small open economy with respect to international markets, but a large open economy relative to the rest of the U.S. The implication is that California's economic activity has no impact on the price of foreign exchange, but can influence the average prices of commodities in other states. Following open-economy modeling convention, we treat the variable PFX as the numeraire price by fixing its value at unity while simultaneously specifying $PRUS_j$ as an endogenous variable. To determine the latter price we employ the simple assumption that California's net export position vis-a-vis the rest of the U.S. is fixed at the level which prevails in the benchmark dataset. Shephard's lemma then implies the supply-demand balance condition:

$$QXUS_i - QMUS_i = \overline{QXUS}_i - \overline{QMUS}_i = \frac{\partial PYX_i}{\partial PRUS_i} QYX_i - \frac{\partial PYM_i}{\partial PRUS_i} QYM_i, \quad (2g)$$

where a bar over a variable indicates its benchmark value. The international net export position is fixed in the same way, with $QXO_i - QMO_i = \overline{QXO}_i - \overline{QMO}_i$, which results in an endogenous short-run balance of payments given by:

$$\textstyle\sum_i [PRUS_i(QXUS_i - QMUS_i) + PFX(QXO_i - QMO_i)].$$

4. Final Demand and Goods Market Closure

Households are modeled as a representative agent who is assumed to have nested CES preferences over consumption of commodities ($q_{i,C}$, at price P_i) and a government good (QG, at price PG):

$$PC = \left[\gamma_{i,CC}^{\sigma_{CG}}\left[\sum_i \gamma_{i,C}^{\sigma_C} P_i^{1-\sigma_C}\right]^{(1-\sigma_{CG})/(1-\sigma_C)} + \gamma_{i,GC}^{\sigma_{CG}} PG^{1-\sigma_{CG}}\right]^{1/(1-\sigma_{CG})}. \quad (3a)$$

Production of both the government good and the investment good (QI, at price PI) are modeled as a CES aggregation of commodities ($q_{i,G}$ and $q_{i,I}$ at price P_i):

$$PG = \left[\sum_i \gamma_{i,G}^{\sigma_G} P_i^{1-\sigma_G}\right]^{1/(1-\sigma_G)}, \quad (3b)$$

$$PI = \left[\sum_i \gamma_{i,I}^{\sigma_I} P_i^{1-\sigma_I}\right]^{1/(1-\sigma_I)}. \quad (3c)$$

Aggregate investment is allocated in fixed proportions to augment the stock of intersectorally mobile capital (QIM, with price PIM) and the j sector-specific capital stocks (QIS_j, with price PIS_j):

$$PI = \nu_{IM} PIM + \sum_j \nu_{j,IS} PIS_j, \quad (3d)$$

which yields the investment supplies

$$QIM = \nu_{IM} QI, \quad (3e)$$

$$QIS_j = \nu_{j,IS} QI. \quad (3f)$$

We assume that the representative agent exhibits constant marginal propensity to save and invest output income. The demands for each type of investment good are determined by an auxiliary constraint on the static general equilibrium problem that forces investment to shrink or expand at the same rate as consumption:

$$QIM/\overline{QIM} = QIS_j/\overline{QIS}_j = QC/\overline{QC}, \quad (3g)$$

by pinning down the prices PIM and PIS_j. Lastly, the market for commodities is closed via the supply-demand balance condition

$$Q_i = \sum_j q_{i,j} + q_{i,C} + q_{i,I} + q_{i,G} \quad (3h)$$

in which the unconditional demands on the right-hand side are given by Shephard's Lemma: $q_{i,j} = \frac{\partial PY_j}{\partial P_i} QY_j$, $q_{i,C} = \frac{\partial PC}{\partial P_i} QC$, $q_{i,I} = \frac{\partial PI}{\partial P_i} QI$ and $q_{i,G} = \frac{\partial PG}{\partial P_i} QG$.

5. Inter-Sectoral Factor Mobility and Static Factor Market Closure

Given the short duration of each time step, the assumption of frictionless inter-sectoral reallocation of labor and capital that is common to most CGE models is unlikely to accurately capture the behavior of factor markets. We therefore introduce sluggish factor inter-sectoral reallocation through the use of constant elasticity of transformation (CET) functions. The supply of mobile capital to each sector is modeled as a CET disaggregation of the aggregate endowment of malleable capital (EX_{KM}, with price RM):

$$RM = \left[\sum_j \kappa_j^{\eta_K} PKM_j^{1-\eta_K}\right]^{1/(1-\eta_K)}. \tag{4a}$$

Sectors' labor supplies are modeled as a CET disaggregation of the aggregate labor endowment (EL, where W is the average wage):

$$W = \left[\sum_j \lambda_j^{\eta_L} (PL_j/\Phi_{j,L})^{1-\eta_L}\right]^{1/(1-\eta_L)}, \tag{4b}$$

where $\Phi_{j,L}$ is a vector of productivity parameters used to model the impact of evacuation losses associated with the storm. The technical coefficients κ and λ are calibrated based on sectors' shares of aggregate labor and mobile capital in the benchmark dataset, while the values of the transformation elasticities η_K and η_L are selected to calibrate the economy's response to the impacts of a severe storm.

The model treats capital as a quasi-fixed factor; accordingly the representative agent's endowments of both sector-specific and intersectorally mobile capital are fixed at each time-step. Traditional CGE models close the labor market either through the "neoclassical" assumption of full employment (perfectly inelastic supply) or "Keynsian" variable employment (perfectly elastic supply at a fixed wage). Neither of these extremes adequately captures the impact of a large transitory shock, which typically induces simultaneous adjustments in both employment and wages. Accordingly, we model labor as a variable factor whose endowment is price responsive. This is achieved by specifying a short-run labor supply curve with elasticity ω_L , which scales the labor supply from its benchmark level, $\overline{EL}$:

$$EL = \overline{EL}\, W^{\omega_L}. \tag{4c}$$

The markets for sector-specific capital, intersectorally mobile capital and labor are closed via the supply-demand balance conditions:

$$\frac{\partial RM}{\partial PKM_j} EX_{KM} = QKM_j = \frac{\partial PY_j}{\partial PKM_j} QY_j, \tag{4d}$$

$$EX_{KS,j} = QKS_j = \frac{\partial PY_j}{\partial PKS_j} QY_j, \tag{4e}$$

$$\frac{\partial W}{\partial PL_j} EL = QL_j = \frac{\partial PY_j}{\partial PL_j} QY_j. \tag{4f}$$

Finally, the levels of aggregate consumption, investment and government activity are determined by the income-expenditure balance condition that constrains the value of final demand to equal the value of factor returns plus tax receipts (a form of a product-income identity at the state level):

$$\sum_j PKS_j\ EX_{KS,j} + RM\ EX_{KM} + W\ EL + \sum_j \tau_j^Y PY_j QY_j = PC\ QC + PI\ QI + PG\ QG \tag{4g}$$

6. The Dynamic Process of the Economy and the Impacts of a Severe Storm

The static equilibrium sub-model made up of eqs. (1)-(4) is embedded within a dynamic process that exogenously updates the productivity parameters $\Phi_{j,Y}$ and the endowments of capital. The endowment of labor is left to adjust endogenously according to eq. (4c), and is not exogenously updated.

In the business as usual (BAU) scenario where no storm occurs, the value of $\Phi_{j,Y}$ is initialized to one in the first period and grows at an annual rate of 1% (0.5% per period) to reflect balanced sectoral productivity improvement. We model the accumulation of stocks of sector-specific and malleable capital ($X_{KS,j,t}$ and $X_{KM,t}$) using the standard perpetual inventory approach. The stocks are initialized by dividing the capital endowments recorded in the benchmark dataset by observed gross rates of return: $X_{KS,j,0} = \overline{EX}_{KS,j}/(r + \delta_{KS,j})$ and $X_{KM,0} = \overline{EX}_{KM}/(r + \delta_{KM})$, where r is the risk-free interest rate in the benchmark year and $\delta_{KS,j}$ and δ_{KM} are the average rates of depreciation of sector-specific and malleable capital derived from BEA data on real cost net stocks and depreciation of detailed fixed assets by detailed industry. One-period-ahead capital stocks are then determined by the balance between geometric depreciation and the level of investment computed by the static equilibrium sub-model at each time step.

A key feature of the capital accumulation process is the incorporation of the property damage associated with a severe storm. We specify destruction of the extant sector-specific and malleable capital stocks in the amount $\Delta X^-_{KS,j,t}$ and $\Delta X^-_{KM,t}$, and exogenous capital reconstruction in the amount $\Delta X^+_{KS,j,t}$ and $\Delta X^+_{KM,t}$. The motion of the economy's capital stocks follows the perpetual inventory equations:

$$X_{KS,j,t+1} = QIS_{j,t} + (1 - \delta_{j,S})(X_{KS,j,t} - \Delta X^-_{KS,j,t} + \Delta X^+_{KS,j,t}). \tag{5a}$$

$$X_{KM,t+1} = QIM_t + (1 - \delta_M)(X_{KM,t} - \Delta X^-_{KM,t} + \Delta X^+_{KM,t}), \tag{5b}$$

which generate the endowments of capital input at each time-step:

$$EX_{KS,j,t} = (r + \delta_{j,KS})X_{KS,j,t}, \tag{5c}$$

$$EX_{KM,t} = (r + \delta_{KM})X_{KM,t}. \tag{5d}$$

We assume that shocks to capital $\Delta X^-_{KS,j}$ and ΔX^-_{KM} occur only in the initial period in which the storm hits ($t = 0$). However, an important difficulty that must be confronted in specifying the shock to the economy is that generalized BI losses stem from both property damage and diminished productivity from having to reorganize production to cope with the exigencies of the post-disaster economic environment. As the literature on modeling the impacts of disasters gives little guidance how to apportion total losses between these two channels of influence, we invoke the principle of insufficient reason and assume that for shocks to the non-utility sectors, losses at $t = 0$ are split evenly between capital and productivity, while for $t > 0$ losses are wholly attributable to reduced productivity. Thus, given an estimate of initial generalized BI losses, $\Lambda_{j,t}$, we compute the shocks from the benchmark sectoral capital demands as:

$$\Delta X^{-}_{KS,j,0} = KLossShr\ \Lambda_{j,0}\overline{QKS}_j/\left(r + \delta_{KS,j}\right), \tag{5e}$$

$$\Delta X^{-}_{KM,0} = KLossShr\ \textstyle\sum_j \Lambda_{j,0}\overline{QKM}_j/(r + \delta_{KM})\ , \tag{5f}$$

where $KLossShr$ is a parameter that takes the value 0.5 for the flood, wind and agricultural components of damage, and is set equal to 1 for utility losses. We assume that reconstruction $\Delta X^{+}_{KS,j}$ and ΔX^{+}_{KM} takes place in the amount of 50% of these one-off losses at $t = 0$, and 25% in each of the two succeeding periods.

A second feature of our model is its representation of persistent generalized BI output losses due to diminished productivity. We simulate these as adverse exogenous productivity shocks whereby sectoral productivity falls short of its benchmark level in proportion to the fractional BI loss:

$$\Phi_{j,Y,t} = \begin{cases} 1 - (1 - KLossShr)\Lambda_{j,t} & t = 0 \\ 1 - \Lambda_{j,t} & t > 0 \end{cases} \tag{5g}$$

where the factor 0.5 reflects our assumption that 50% of the BI loss in the first period is attributable to capital stock damage. With the storm, the industries in the model, instead of becoming increasingly productive as in the BAU scenario, see their productivity decline in the first six months after the storm hits, and then recover only to initial levels. When simulating the impact of wind and flood damage as well as damage to crops and livestock, we use 5(e-g) to specify capital and output losses in all sectors. When simulating the impact of disruptions in utility service, the capital shocks (5e) and (5f) are applied only to the supplying sector (e.g., electric power, wastewater, etc.) with $KLossShr = 1$, while the remaining downstream purchasing sectors are assumed to suffer the pure productivity impacts specified in (5g). Finally, losses associated with the evacuation of firms' employees are modeled as productivity impacts that increase firms' labor costs by driving a wedge between labor supply and demand:

$$\Phi_{j,L,t} = 1 - \Lambda_{j,t}, \tag{5h}$$

without direct losses of capital or output.

7. Model Calibration, Formulation and Solution

The vectors of technical coefficients $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$, $\boldsymbol{\gamma}$, $\boldsymbol{\kappa}$ and $\boldsymbol{\lambda}$ in eqs. (1)-(4) are calibrated using an IMPLAN social accounting matrix for the state of California for the year 2007 (Minnesota IMPLAN Group, 2007) in conjunction with values of the elasticities of substitution and transformation drawn from Rose and Liao

(2005) and Rose et al. (2009). The latter parameters are summarized in table 2. The model is formulated as a mixed complementarity problem using the MPSGE subsystem for GAMS (Rutherford, 1999; Brooke et al., 1998) and is solved using the PATH solver (Ferris et al., 2000).

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Table 1. CGE Model Sectors

Agriculture
- *Field Crops*
  - Oilseed farming
  - Grain farming
  - Vegetable & melon farming
  - Sugarcane & sugar beet farming
- *Tree & Other Crops*
  - Fruit farming
  - Tree nut farming
  - Greenhouse nursery & floriculture
  - All other crop farming
- *Other Agriculture*
  - Livestock
  - Forestry & Logging
  - Fishing- Hunting & Trapping
  - Agriculture & Forestry svcs

Energy
- Electric power gen./trans./dist.
- *Fuels* ($\mathcal{F}$)
  - Oil & gas extraction
  - Natural gas distribution
  - Petroleum refineries
  - Petroleum & coal prod

Transportation
- *Transport* ($\mathcal{TR}$)
  - Air transportation
  - Rail Transportation
  - Water transportation
  - Truck transportation
- *Other Transport Services* ($\mathcal{OT}$)
  - Transit & ground passengers
  - Pipeline transportation
  - Sightseeing transportation
  - Couriers & messengers
  - Warehousing & storage

Materials
- *Chemicals* ($\mathcal{CM}$)
  - Chemical Manufacturing
  - Plastics & rubber prod
- *Other Materials* ($\mathcal{OM}$)
  - Mining
  - Mining services
  - Water Services
  - Sewage & Other System
  - Nonresidential Construction
  - Residential Construction
  - Food products
  - Beverage & Tobacco
  - Textile Mills
  - Textile Products
  - Leather & Allied
  - Wood Products
  - Paper Manufacturing
  - Printing & Related
  - Nonmetal mineral prod
  - Primary metal mfg
  - Fabricated metal prod
  - Machinery mfg
  - Computer & other electronics
  - Electrical equip & appliances
  - Transportation equipment
  - Furniture & related prod
  - Miscellaneous mfg

Services
- *Financial Services* ($\mathcal{FS}$)
  - Monetary authorities
  - Credit intermediation & related
  - Securities & other financial svcs
  - Insurance carriers & related
  - Funds- trusts & other financial svcs
  - Real estate
  - Rental & leasing svcs
  - Lessors of nonfinancial intangible assets
- *Other Services* ($\mathcal{OS}$)
  - Wholesale Trade
  - Motor vehicles & parts dealers
  - Furniture & home furnishings
  - Electronics & appliances stores
  - Bldg materials & garden dealers
  - Food & beverage stores
  - Health & personal care stores
  - Gasoline stations
  - Clothing & accessories stores
  - Sports- hobby- book & music stores
  - General merchandise stores
  - Misc retailers
  - Non-store retailers
  - Publishing industries
  - Motion picture & sound recording
  - Radio & television broadcasting
  - Cable & other subscription programming
  - Internet publishing & broadcasting
  - Telecommunications
  - Internet & data process svcs
  - Other information services
  - Professional- scientific & tech svcs
  - Management of companies
  - Admin support svcs
  - Waste mgmt & remediation svcs
  - Educational svcs
  - Ambulatory health care
  - Hospitals
  - Nursing & residential care
  - Social assistance
  - Performing arts & spectator sports
  - Museums & similar
  - Amusement, gambling & recreation
  - Accommodations
  - Food svcs & drinking places
  - Repair & maintenance
  - Personal & laundry svcs
  - Religious, grantmaking & similar orgs
  - Private households
  - Government & non NAICs
  - Owner occupied dwellings

Table 2. Elasticities of Substitution and Transformation

	η_{XX}	η_{XD}	σ_{MM}	σ_{MD}	σ_{KLE}	σ_{KELM}	σ_{FUEL}	σ_{E}	σ_{M}	σ_{SRV}	σ_{OT}	σ_{TRN}	σ_{FS}	σ_{OS}	σ_{CM}	σ_{OM}	σ_{TR}	σ_{OT}
Agriculture	0.55	0.75	1.00	2.00	0.55	0.64	0.55	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
Mining	0.55	0.75	0.49	1.00	0.38	0.55	0.55	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
Construction	0.45	0.45	0.45	0.45	0.25	0.10	0.55	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Food Processing	0.90	0.90	0.57	1.25	0.48	0.28	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Chemicals	0.38	1.00	0.55	1.00	0.38	0.30	0.55	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Petroleum Refining	0.38	1.00	0.55	1.00	0.38	0.30	0.55	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Other Non-Durable Mfg	0.38	1.00	0.75	1.50	0.35	0.35	0.55	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Primary Metals	0.38	1.00	0.90	1.25	0.61	0.41	0.55	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Semiconductors	0.38	1.00	0.90	1.25	0.32	0.49	0.55	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Other Durable Mfg	0.38	1.00	1.00	1.00	0.49	0.15	0.05	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Local Private Transportation	1.00	1.00	0.55	1.00	0.55	0.27	0.55	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Other Transportation	1.00	1.00	0.55	1.00	0.55	0.27	0.55	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Communication	1.00	1.00	0.55	1.00	0.55	0.27	0.55	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Private Electric Utilities	1.00	1.00	0.55	1.00	0.55	0.27	0.55	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Gas Utilities	0.38	0.55	0.10	1.50	0.25	0.10	0.55	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Water Utilities	0.38	0.55	0.10	1.50	0.13	0.38	0.55	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Sanitary Services	0.38	0.55	0.10	1.50	0.13	0.41	0.55	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Wholesale Trade	0.38	0.55	0.10	1.50	0.25	0.41	0.55	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Retail Trade	1.00	1.00	0.55	1.00	1.14	0.13	0.55	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Real Estate	1.00	1.00	0.55	1.00	1.14	0.13	0.55	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Banking & Credit	1.00	1.00	0.55	1.00	0.83	0.13	0.55	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Security Brokers	1.00	1.00	0.55	1.00	0.15	0.13	0.55	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Insurance	1.00	1.00	0.55	1.00	0.55	0.13	0.55	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Owner Occupied Dwellings	1.00	1.00	0.55	1.00	0.55	0.13	0.55	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Hotel and Restaurants	1.00	1.00	0.55	1.00	0.83	0.13	0.55	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Personal Services	1.00	1.00	0.55	1.00	0.25	0.13	0.55	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Business Services	1.00	1.00	0.55	1.00	0.55	0.13	0.55	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Information	1.00	1.00	0.55	1.00	0.55	0.13	0.55	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Entertainment	1.00	1.00	0.55	1.00	0.55	0.13	0.55	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Education	1.00	1.00	0.55	1.00	0.55	0.13	0.55	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Health & Social Services	1.00	1.00	0.55	1.00	0.55	0.13	0.55	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
State & Local Electric Utilities	1.00	1.00	0.55	1.00	0.55	0.13	0.55	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Local Public Transportation	1.00	1.00	0.55	1.00	0.55	0.13	0.55	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Government	1.00	1.00	0.55	1.00	0.55	0.13	0.55	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16

Elasticities of substitution between capital and labor σ_{KL} = 1; between sector-specific and intersectorally mobile capital σ_{KK} = 0.2-1; among inputs to final use sectors: goods consumption σ_{C} = 0.1, government vs. private consumption σ_{CG} = 0.1, investment σ_{I} = 0.1, government σ_{G} = 0.1. Elasticities of inter-sectoral factor supply transformation: labor η_{L} = 0.5, mobile capital η_{K}= 0.5. Uncompensated labor supply elasticity ω_{L} = 0.25.