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The value of the high Aswan Dam to the Egyptian economy

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ABSTRACT

The High Aswan Dam converted a variable and uncertain flow of Nile river water into a predictable and controllable water supply stored in Lake Nasser. We use a computable general equilibrium model of the Egyptian economy to estimate the economic impact of the High Aswan Dam. We compare the actual 1997 economy to the 1997 economy as it would have been if historical pre-dam Nile flows (drawn from a 72 year portrait) had applied (i.e., the Dam had not been built). The steady water supply sustained by the High Aswan Dam increased transport productivity, and year round availability of predictable and adequate water sustained a shift towards more valuable summer crops. These static effects are worth EGP 4.9 billion. Investments in transport and agriculture increased as a consequence; these investments, assuming that Egypt is a small open economy, added another EGP 1.1 billion to the value of the Dam. The risk premium on the reduced variability is estimated to be EGP 1.1 billion for a modest risk aversion, and perhaps EGP 4.4 billion for a high risk aversion. The total gain of EGP 7.1 billion to 10.3 EGP billion equals 2.7% to 4.0% of annual GDP in 1997.

1. Introduction and overview

The High Aswan Dam effectively converted a highly variable intra-annual Nile flow (that was also variable from year to year) into a predictable source of a constant supply. Water sitting behind the Dam is available for release any time during the year, so seasonal variation in Nile flows can be manipulated to deliver supplies of water that match the optimal intra-annual demand pattern. This supply of water is also large enough to reduce most annual variability essentially to zero. The question to be addressed here is: what is the value to the Egyptian economy of the resulting reduction in uncertainty; i.e., what is the economic value of reduced risk in the supply of water? Indeed, what is the economic value of water security to the Egyptian people?

The purpose of this study is to generate an improved understanding of the impact of the High Aswan Dam on Egypt from an economy-wide perspective. This paper is one of a series of studies commissioned by the World Bank, each doing an ex-post evaluation of a selected dam. While the other studies use a simple costing and multiplier approach, we use a computable general equilibrium (CGE) model of Egypt to conduct comparative-static simulations of Egypt's economy with and without the High Aswan Dam.[1] The analysis covered the impact of the dam through the following channels: changes in the supplies of

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[1] Note that the scenarios without the High Aswan Dam do take account of the low Aswan Dam of 1903.

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Table 1 – Water allocation (in billion cubic metre) under Egypt–Sudan agreement

Average annual Nile Flow	$84.0 \cdot 10^9$ m^3
Reservoir losses due to evaporation and seepage	$-10.0 \cdot 10^9$ m^3
Net water availability per annum	$74.0 \cdot 10^9$ m^3
Allotment to the Sudan	$18.5 \cdot 10^9$ m^3
Allotment to Egypt	$55.5 \cdot 10^9$ m^3
Total water usage per annum	$74.0 \cdot 10^9$ m^3

irrigated land and water, changes in the supplies of electric power, changes in yields and production technology (primarily changes in fertilizer use), and changes in the real costs associated with other investments (e.g., in flood control and hydropower) that would have been likely in absence of the Dam. In addition, the analysis considered the implications of the reasonable expectation that the performance of Egypt's economy in each year without the Dam would have depended on highly variable flows in the Nile. The CGE model was constructed around a 1996/97 Social Accounting Matrix (SAM) for Egypt. For our simulations, we drew upon historical data on Nile flows and assessments of various aspects of the costs and benefits associated with the High Aswan Dam.

Our analysis explored the main effects, both costs and benefits, of the Dam during a typical year in its "productive" lifetime. We divided the effects into direct and indirect. The impact indicators included production and trade, but they also included disaggregated household incomes and their distribution. In addition, we computed a risk premium for variability in the flow of the Nile that would have characterized recent history in the absence of the Dam. To compute these premiums, we assumed that economic agents try to maximize expected utility so that they incorporate risk explicitly into their investment and consumption decisions. We computed a "certainty equivalent" outcome for which utility (for our economic agents) equals expected utility over a probabilistically weighted range of plausible outcomes. If the agents are risk-averse, then their certainty-equivalent incomes will be less than the expected value of incomes. They would, as a result, be willing to pay to avoid the risk; this is the so-called risk premium.

A number of papers have been written exploring the most efficient use of the High Aswan Dam; see, for example, Thomas and Revelle (1966), Oven–Thompson, et al. (1982), Perry (1996), or Ali et al. (2001). These studies do not examine the benefit-cost of the project; they take the Dam as a fact of life and examine the optimal way to use its resources. El Mallakh (1959) and Owen (1964) present economy-wide analyses of the impacts of the High Aswan project on the Egyptian economy, but we use newer data. Wichelns (2002) also presents an analysis of the economic impacts of the High Aswan Dam, but based on a partial equilibrium model, while we use a computable general equilibrium (CGE) framework.

There are only a few studies that use a CGE to study water resources. Decaluwe et al. (1999) analyze the effect of water pricing policies on demand and supply of water in Morocco. Daio and Roe (2003) use an inter-temporal CGE model for Morocco focusing on water and trade policies. Seung et al. (2000) use a dynamic CGE model to estimate the welfare gains of reallocating water from agriculture to recreational use for the Stillwater National Wildlife Refuge in Nevada. For the Arkansas River Basin, Goodman (2000) shows that temporary water transfers are less costly than building new dams. Gómez et al. (2004) analyze the welfare gains by improved allocation of water rights for the Balearic Islands. Letsoalo et al. (2007) study tax reform in South Africa and find that a water tax would reduce water consumption and, if recycled by reduction in food taxes, stimulate economic growth and reduce the real income gap between rich and poor. Berrittella et al. (2007) use a *global* CGE model including water resources to analyze the economic impact of restricted water supply for water-short regions. Berrittella et al. (2005) use the same model to investigate the economic implications of water pricing policies, and Berrittella et al. (2006) study the South-North Water Transfer project in China. Feng et al. (in press) look at the same issue with a recursive-dynamic CGE with two regions for China but no abroad. None of these papers looks at variability in water supply, and so none explores the economic value of reduced variability.

We proceed here as follows. Section 2 provides a general background on the High Aswan Dam and a review of the impacts of the Dam. Section 3 presents the CGE model that is used in this study. Section 4 shows static results derived from

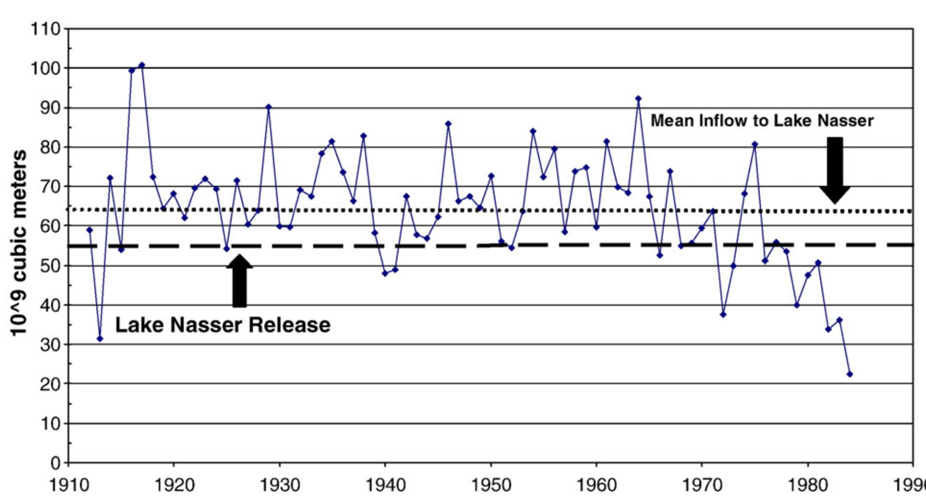

Fig. 1 – The Nile flow at Aswan with and without the High Aswan Dam.

the simulations that were used to assess how Egypt's economy would have performed in 1996/97 without the Dam, including explicit consideration of how the economy would have been affected by year-to-year variations in Nile flows. Section 5 expands the analysis by including the dynamic effects. In Section 6, we compute the "risk premium" of the High Aswan Dam before concluding remarks are offered in Section 7.

2. Egypt and the High Aswan Dam

Analysis of the possibility of building the High Aswan Dam began after the July 1952 Revolution. The World Bank initially agreed to finance the huge project, but the Bank ultimately withdrew its support. Funds required to finance the project became available after the nationalization of the Suez Canal, and the Soviet Union provided technical assistance. The foundation stone of the High Aswan Dam was laid on January 9, 1960, and the ceremony that marked its completion was held on January 15, 1971. The total cost of its construction was EGP 500 million. Fifty thousand engineers and workers took part in the implementation of this giant project. The Dam is a rock-filled structure built south of Aswan. It is 3600 m long and pyramidal in shape (980 m wide at the base and 40 m wide at the top), and it rises 111 m above the Nile floor and 196 m above sea level.

Water is released through six tunnels that are each 14 m in diameter. These releases both regulate flow and produce electrical power from 12 generating units. A great lake was created front of the High Aswan Dam. Dubbed Lake Nasser, it has a storage capacity of 164 billion cubic meters (BCM) and it reaches a maximum depth of 182 m. For purposes of this analysis, it is important to note that Lake Nasser is a large reservoir in the midst of a large desert with a large surface area. Enormous amounts of evaporation are therefore one of its main characteristics.

In 1959, Egypt and Sudan signed the Nile Waters Agreement, a bi-lateral agreement to allocate the flow of the Nile as it crosses the Egyptian–Sudanese border. The agreement assumed the availability and proposed allocations shown in Table 1. Egypt is allowed an annual release equal 55.5 BCM. With the active storage behind the High Aswan Dam, reservoir design theory suggests that a firm yield (i.e., a constant annual release with 100% reliability) of 55.5 MCM is obtainable at the cost of evaporating 10 BCM (12.5% of the annual flow). Fig. 1 shows the impact of High Aswan Dam on water supply availability to Egypt. The variable line shows the Nile flow as it would have been observed without the High Aswan Dam (a reflection of the 72 year historical record before 1971). The lower straight line shows the actual Nile flow after completion of the High Aswan Dam and estimates the flow that would have been experienced if the Dam been built before 1971. The difference between the two straight lines is evaporation from Lake Nasser.

To match the cropping season of Egypt as well as the seasonality of the Nile flows, we have divided the Nile into two seasonal flows: flood (from August to January) and summer (from February to July). The flood period sees approximately 70% of Nile flow at Aswan; its source is the Blue Nile with its headwater in Ethiopia. Summer flow comes almost exclusively from the White Nile; it exits the Sudd wetlands in Southern Sudan after losing 50% of its volume through evapotranspiration by wetland vegetation.

Table 2 – Cropped area

	1960	1995
Wheat	1387	1829
Maize	1727	1906
Millet	469	346
Rice	799	1276
Cotton	1751	884
Sugar cane	122	274
Total	6255	6515

The economic benefits[2] of providing a highly reliable and non-flooding water supply to Egypt are easily identified. They include:

- Saving Egypt from devastating floods and the resulting loss of summer harvests, damage to infrastructure, and loss of life.
- Reclaiming about 1.2 feddans (4.8 million square meters) of arable land.
- Irrigating about 850 thousand feddans that would have been irrigated from existing basins.
- Increasing rice and sugar cane production substantially.
- Generating an average of 8 billion kilowatt/hour for industry and the electrification of all towns and villages in Egypt.
- Facilitating navigation up and down the Nile all the year round.

Table 2 compares actual crop areas in 1995, 25 years after the High Aswan Dam was completed, with pre-Dam areas. It shows major increases in wheat, maize, rice and sugar cane areas and a major decrease in the cotton area. The net addition in cropped area before and after the dam is less then the expanded irrigation figures mentioned above. This is mainly attributed to urban encroachment on cultivated land and the difficulties encountered with reclaiming new lands. Fig. 2 shows that little water was available in Egypt during the summer cropping season before the High Aswan Dam was constructed, and that the Nile Flood came just at the end of the summer season posing a threat to the harvest.

Table 3 shows a typical annual cropping calendar after the Dam. One can compare this detailed water accounting with the cropping pattern from Table 2. Notice the changes in cropping areas between summer and winter; more importantly, notice the water use between the seasons. Summer crops use 29.4 BCM compared to 17.0 for winter crops. The increased water supply not only allowed more cropped area in the summer, but also generated greater yields and allowed for shifting to more valuable but water-intense crops such as rice. Fig. 2 also shows how the cropping pattern after the Dam is almost completely out of phase with the natural seasonal

[2] Strictly, these are not benefits per se, but rather changes that would have a beneficial effect on welfare in Egypt.

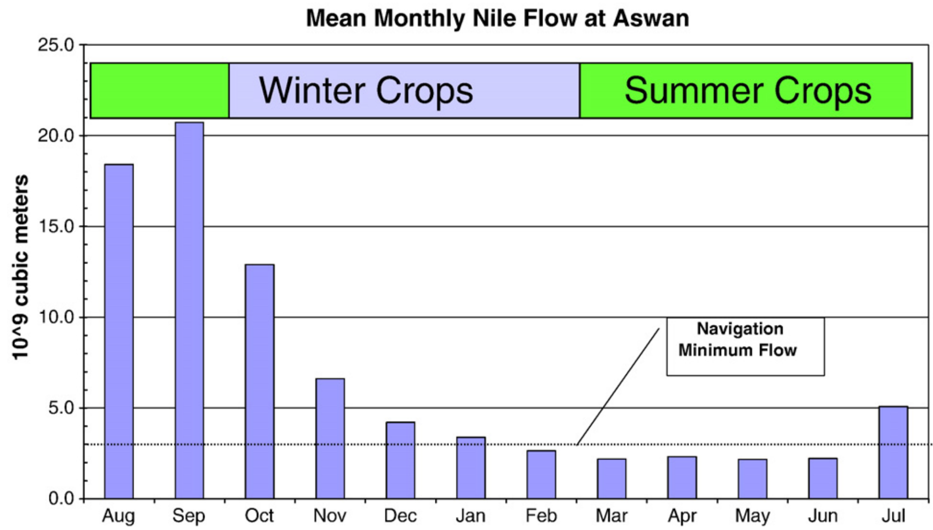

Fig. 2 – Nile flow and growing seasons.

pattern of Nile flow. This is only possible due to the within-year water storage provided by the Dam. However, the increase in cropped area also implies lower average yields because more marginal areas were taken into production. The latter effect dominates in the simulations below.

3. Overview of the CGE model

Computable general equilibrium models (CGEs) are solvable numerically and provide a full accounting of production, consumption and trade in a particular economy. Since the first applications in the mid-1970s, this class of models has become widely used in policy analysis in developing countries. This analysis is based on an extended version of IFPRI's Standard CGE model, written in the GAMS (General Algebraic Modeling System) software. The computer code separates the model from the database – with a social accounting matrix (SAM) as its main component – making it easy to apply the model in new settings. For a more detailed discussion of the model and application see Robinson et al. (2001) and Lofgren et al. (2001).

The CGE model that we employed for Egypt followed the disaggregation of a SAM and explains all payments that are recorded in the SAM. It was written as a set of simultaneous equations, many of which are non-linear. There is no social planner in the model. The equations define the behavior of the different actors. In part, this behavior follows simple rules captured by fixed coefficients (for example, *ad valorem* tax rates). For production and consumption decisions, behavior is captured by non-linear, first-order optimality conditions of profit and utility maximization. The equations also include a set of constraints that have to be satisfied by the system as a whole but which are not necessarily considered by any individual actor. These "system constraints" work to define equilibrium in markets for factors and commodities, and macroeconomic aggregates (balances for savings-investment, the government, and the current-account of the rest of the world).

The standard CGE model is characterized by flexible disaggregation and pre-programmed alternative rules for clearing factor markets and macro accounts. Fig. 3 provides a simplified picture of the links between the major building blocks of the model employed here. The disaggregation of activities, (representative) households, factors, and commodities – the blocks on the left side of the figure – is determined by the disaggregation of the SAM. The arrows represent payment flows. With the exception of taxes, transfers and savings, the model also includes "real" flows (for a factor service or a commodity) that go in the opposite direction. The activities (which carry out production) allocate their income, earned from output sales, to intermediate inputs and factors.

Producers are assumed to maximize profits subject to prices and a nested technology in three levels as shown in Fig. 4. At the top of the nest, output is either a Leontief or a CES function of aggregates of value-added and intermediate inputs. At the second level, aggregate value-added is a constant elasticity of substitution (CES) function of factors, whereas the aggregate intermediate input is a Leontief function of disaggregated intermediate inputs. A third level is specified in one area: agricultural land and water are combined in fixed proportions to form a land-water aggregate that enters as a factor on the second level. Although the water use per crop is fixed, we specify four possible land-water technology combinations for each crop, with assumed declining marginal productivity of water, as shown in Fig. 5. In effect, the model specifies the choice of land-water combinations by crop as a linear programming problem.[3] The farmer chooses the least-cost land-water technology for each crop, given the "prices" of land and water.[4] The model solves for land rental

[3] The net addition in cropped area before and after the dam is less then the expanded irrigation figures mentioned above. This is mainly attributed to urban encroachment on cultivated land and the difficulties encountered with reclaiming new lands.

[4] The linear programming problem is translated in the CGE model into a mixed complementarity problem (MCP) and the overall model is solved using an MCP algorithm (PATH), with the linear programming complementary slackness conditions explicitly specified. See Lofgren and Robinson (1999).

Table 3 – Water use: 1995

Crop sectors	Crop water consumption (m^3 per feddan)	1993 crop area feddans	Water consumption (BCM)	Water withdrawal (BCM)
Winter crops				
Wheat	1816.38	1,829,232	3.3	5.1
Legumes	1461.37	323,700	0.5	0.7
Long berseem	2538.18	1,668,846	4.2	6.5
Short berseem	903.47	642,643	0.6	0.9
Winter vegetables	1489.10	508,040	0.8	1.2
Other winter	1286.65	75,429	0.1	0.1
Perennial-winter	2030.51	794,032	1.6	2.5
Total winter		5,841,922	11.1	17.0
Summer crops				
Cotton	3025.81	884,310	2.7	4.1
Rice	4691.40	1,276,295	6.0	9.2
Maize + Sorghum	2525.84	2,252,043	5.7	8.8
Summer Veg	1939.89	558,549	1.1	1.7
Other Summer	2473.08	286,106	0.7	1.1
Perennial-summer	3770.94	794,032	3.0	4.6
Total Summer		5,257,303	19.1	29.4
Total annual		11,099,225	30.2	46.5

rates and the shadow price (or scarcity price) of water that ensures the efficient allocation of available water and land across competing uses (i.e., crops in this model, since non-agricultural demand for water is assumed to always be met).

The model distinguishes two types of land and water: summer land, winter land, summer water, and winter water. With the exception of vegetables and sugar cane, the various crops are season-specific-they are either grown in the winter or summer, and only use land and water in one season. The aggregate supplies of winter and summer land and water are specified separately, and the model generates separate shadow prices for winter and summer land and water. Since the High Aswan Dam permits Egypt to make the seasonal flows of water more even over the year, the model is specified so that, for the with-dam scenario, the total High Aswan Dam release of 55.5 is available to be allocated to either summer or winter crops. Without the dam, the winter flood is assumed to generate an excess supply of water in the winter, with corresponding water scarcity in the summer.

Given the solution to each sectoral linear programming problem, the model generates a land-water aggregate for each agricultural sector that is then assumed to enter a neoclassical production function along with labor and capital. The rental rate of the land-water aggregate in the model is assumed to consist of the separate values of the land and water components, valued at their shadow prices. Agricultural technology in the model is thus specified as a nested function with a Leontief demand for intermediate inputs, a CES function of value added (labor, capital, and land-water aggregate), and a linear programming specification of land and water use. In the base solution, it is assumed that water is in excess supply and hence has a shadow price of zero. In this case, the entire value of the land-water aggregate is attributed to land.

Given the assumption that they are small relative to the market, producers take prices as given when making their decisions. After meeting home consumption demands, the outputs are allocated between the domestic market and exports in shares that respond to changes in the ratio between the prices that the producers receive when selling domestically and abroad. In world markets, the supplies of exports are absorbed by infinitely elastic demands at fixed prices (the small-country assumption). Domestic market demands (for investment, private consumption, government consumption, and intermediate input use) are met by supplies from domestic producers and the rest of the world (imports). For any commodity, the ratio between the demands for imports and domestic output responds to changes in the relative prices of imports and domestic output that is sold at home. In world markets, import demand is met by an infinitely elastic supply of imports at fixed prices. In the domestic markets for products of domestic origin, flexible prices assure that the quantities demanded and supplied are equal.[5] We use a long-term closure, with endogenous wages and an exogenous rate of return on capital.

The factor costs of the producers are passed on as receipts to the household block in shares that reflect endowments. In addition to factor incomes, the household block may receive transfers from the government (which are CPI-indexed), the rest

[5] In terms of functional forms, the Standard model uses a CES function to capture the aggregation of imports and output sold domestically to a composite commodity, and a CET function to capture the transformation of output into exports and domestic sales. Without any change in the GAMS code, the model can handle databases with commodities that are only exported (no domestic sales of output), only sold domestically (no exports), or only imported (no domestic production).

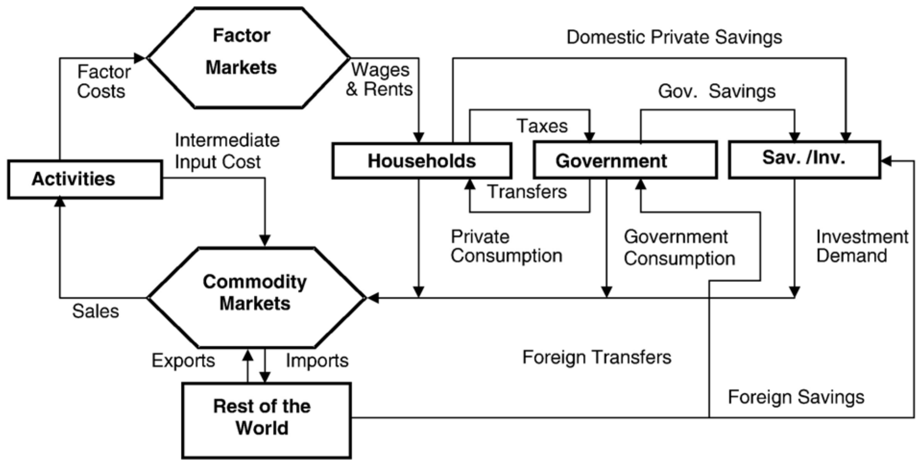

Fig. 3 – Structure of payment flows in the Standard CGE model.

of the world (fixed in foreign currency), and other households. These incomes may be spent on savings, direct taxes, transfers to other institutions, and, for the representative household, consumption. Savings, direct taxes, and transfers are modeled as fixed income shares. Consumption is split across different commodities, both home-consumed and market-purchased, according to LES (Linear-Expenditure-System) demand functions (derived from utility maximization).

The government receives direct taxes from the households and transfers from the rest of the world (fixed in foreign currency). It then spends this income on consumption (typically fixed in real terms), transfers to households, and savings. The rest of the world (more specifically the current account of the balance of payments) receives foreign currency for the imports of the model country, and then spends these earnings on exports from the model country, transfers to the model country's government, and on "foreign savings" (i.e., the current account deficit). Together the government, enterprises, and the rest of the world may play an important role in the distributional process, by "filtering" factor incomes on their way to the representative households and by directly taxing or transferring resources to the representative households. Finally, the savings-investment account collects savings from all institutions and uses these to finance domestic investment.

The modeler has the option to choose among a relatively large number of pre-programmed alternative closure rules for the factor markets and the three macro accounts of the model, the (current) government balance, the balance of the rest of the world (the current account of the balance of payments, which includes the trade balance), and the savings-investment balance.

The model is used for comparative static analysis, implying that the impact of the shock (or the combination of shocks) that is being simulated is found by comparing the model solutions with and without the shock(s). Each model solution provides an extensive set of economic indicators, including GDP; sectoral production and trade volumes; factor employment; consumption and incomes for representative households; commodity prices; and factor wages. We use changes in GDP to approximate changes in the sum of consumer and producer surplus. This aggregates the various benefits listed above.

4. The static impact of the High Aswan Dam on the Egyptian economy

This section presents the results of simulations to assess how Egypt's economy would have performed in 1996/97 without the dam and how the economy, without the dam, would have been affected by year-to-year variations in Nile flows. Variations in Nile flows affect the economy through availability of water supplies for agriculture, the generation of hydropower, navigation, and tourism. Along these lines, we applied a set of historical data about the Nile flows to determine how the Egyptian economy would have fared without the dam. The simulations include the effects of the "original" Aswan Dam, which was built in 1902 and in 1933 raised to store 4 BCM (3% of the Lake Nasser storage). It was only electrified in 1960 in conjunction with the building of the High Aswan Dam. The

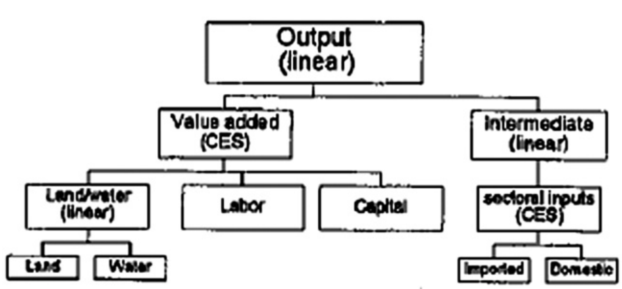

Fig. 4 – Sectoral production technology.

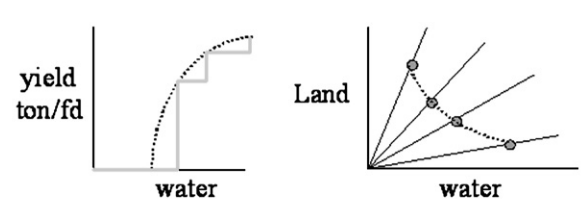

Fig. 5 – Land and water technology.

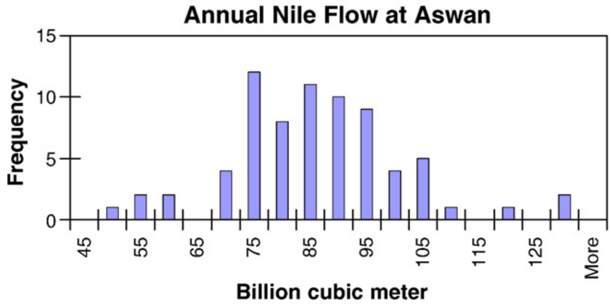

Fig. 6 – Histogram of annual Nile Flow at Aswan.

Aswan Dam power station has an installed capacity of 345 MW as compared to 2100 MW of the High Dam power Station.

The simulation shocks the economy in two ways: the removal of Lake Nasser reservoir storage, and the hydropower produced by the High Aswan Dam Power Station. Capital investments in improved irrigation infrastructure that would allow for significantly more summer irrigation are also removed because these investments would not been made given the uncertainty of summer flows. The underlying resources for these investments would, though, be available to Egypt, and so the simulations allow the agricultural sector to take advantage of high summer flows when the do appear in the 72 year series. This means that the shock is measured in the "economic impact" accounts only for capital expended on the High Aswan Dam and Power Station and does not include, necessarily, a reduction the associated irrigation investment.

Fig. 6 is a histogram of the 72 years of historic Nile flow used as input to the model. In all simulations, the "shock" reduced the supply of summer water in ways that were calibrated to historical data on summer water flows. In effect, the removal of the dam was assumed to force Egypt to use less water in the summer season while it watched an excess supply of water flow into the Mediterranean Sea during the winter. See Fig. 2. The shock was applied to agriculture, transport, tourism, and power generation.

Each set of simulations produced 72 sets of results — one for each of the 72 years of historical data on Nile flows. Our analysis therefore captures the results of one "experiment" for each specification of summer water availability based on historical data. For these experiments, the output loss in the summer arising from flooding in the previous winter was ignored. So, the experiments we report underestimate the gains from the dam, or the losses associated with "removing" the dam. Table 4 summarizes the results for all simulations. The "base" column shows values from the 1997 SAM for Egypt, and the other columns show the mean value and standard deviation of selected variables for the set of simulations using historical flow data.

The results show that expected annual "Economy-wide" GDP would have been smaller in 1997 if the High Aswan Dam had not been there. Examining the major sectors separately shows that expected annual agricultural production would have been larger while the burden of the water-related shocks would have fallen on the non-agriculture sectors: lower in power generation, transportation, and tourism. This is due to

Table 4 – Simulation results

	With HAD	Historic flows without HAD	
	Base	Mean	Std. Dev.
Consumption	196.3	191.5	4.0
Exports	54.6	53.5	1.0
Imports	−62.0	−60.9	1.0
Real GDP	260.0	255.1	4.0
GDP at factor cost	238.8	235.0	5.2
Agriculture**	42.3	43.2	4.8
Winter	12.4	12.5	0.3
Summer	16.9	17.8	4.8
Perennial	5.7	5.7	0.1
Non-agriculture	196.5	191.8	3.0

the fact that the sectoral response functions to Nile water are not symmetric around the BASE "constant" summer water supply of approximate 30 BCM.

The burden of the shocks falls on the non-agriculture sectors, with declines in power, transportation, and tourism. Agriculture actually gains from the "removal" of the High Aswan Dam, and high-valued summer crops particularly gain. The increase in the value of agricultural production arises from the fact that land used in high-value crops has a higher marginal product than land used in low value crops. With the removal of summer water, farmers grow only high value crops, increasing the average value of agricultural output. Put another way, the High Aswan Dam allowed Egypt to support growing low value crops. The dam also allowed Egypt to follow a pattern of distorted policies (e.g. Owen, 1964). Particularly, Egypt has high tariffs on food imports. With uncertain water flows, restricted in the summer, production is restricted to high value crops, especially summer crops — low value crops can no longer compete, despite protectionism. The decrease in distortions increases efficiency in agriculture, although not enough to offset the losses in electric power, tourism, and transportation. Overall, the dam generates significant gains.

The model assumed that irrigated land can change each year with the water available and that it would produce identical yields (per hectare) with and without the Dam. Given these assumptions, the agricultural sector utilized all summer water according to a monotonically increasing function. A land-water aggregate allowed the model to grow more water intensive crops for high summer water supply even if the land constraint was binding. For years with low summer water

Table 5 – Expected annual net benefits of HAD from CGE analysis 1997

Expected REAL GDP with HAD	260.0 EGP billion (1997)
Expected REAL GDP without HAD	255.1 EGP billion (1997)
Net expected REAL GDP from HAD	4.9 EGP billion(1997)

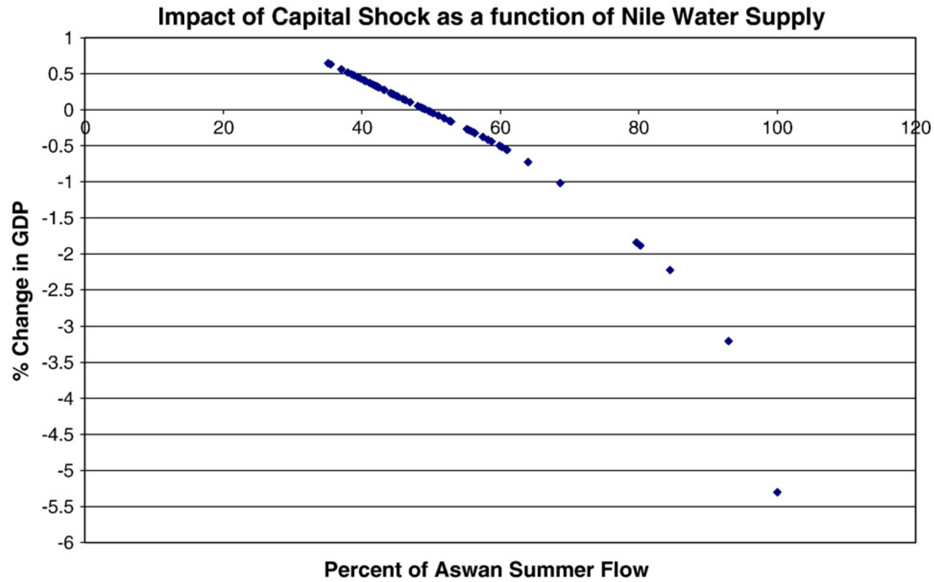

Fig. 7 – Impact of capital shock as a function of Nile Water supply.

supplies, though, the model optimized the land-water aggregate so that farmers grew only high-value crops, increasing the average value of agricultural output. Put another way, the Dam allowed Egypt to even the water flow over the year and to support growing low value crops. Moreover, agriculture is subsidized in Egypt, and hence in the calibration of our base year. A reduction of the water supply would act as a tax on agriculture, or as reduction of the subsidies. Reducing distortionary subsidies is good for the economy, which explains the positive results for GDP.

For the non-agriculture sectors, power, transportation, and tourism, the response function was not monotonically increasing with Nile Flow. Without the Dam, the associated power station would not have been built and the (lower) Aswan Dam power station would have a capacity constraint close to the mean flow of the Nile. Transportation and tourism had a minimum low flow constraint and then displayed constant returns for increasing Nile Flow up to a point where flooding actual decreased production. (Flooding is not considered in this analysis.). However, the gain in agriculture was not enough to offset the losses in electric power, tourism, and transportation. Overall, the High Aswan Dam had a positive effect on the Egyptian economy.

Table 5 shows that the difference in expected values of real GDP with and without High Aswan Dam across our simulations is 4.9 EGP Billion. This amounts to 2% of 1997 GDP. Overall, the dam generates significant gains.

Table 6 – Expected annual net benefits with and without capital shock from CGE analysis 1997

Expected REAL GDP with full capital	255.1 EGP billion (1997)
Expected REAL GDP with capital shock	254.0 EGP billion (1997)
Net expected REAL GDP from capital shock	1.1 EGP billion (1997)

5. The dynamic effects of the High Aswan Dam on the Egyptian economy

The previous section focused attention on the static economic effects of the High Aswan Dam; i.e., we shocked water supply only and assumed its affected only the productivity of certain sectors. However, one might argue that investment should increase in sectors where the High Aswan Dam increased productivity and reduced the variability. We therefore ran a second set of simulations that were identical to those described above except that we shocked the capital stock as well. Because we use the small-country assumption of a fixed interest rate, capital is only shocked in those sectors that would be directly affected by water supply.

Hansen (1991) showed data on investment per sector in Egypt. After completion of the High Aswan Dam, investment in agriculture and transport indeed increased by 50% and 120%, respectively, whereas total investment increased by only 14%. We interpret these observations as the direct result of the High Aswan Dam, and proportionally extrapolate this from 1971, the completion of the Dam, to our calibration year of 1997. We thereby find that invested capital would have been about 25% lower in agriculture and 50% lower in transport if the Dam had not be constructed.[6]

The impact of this negative capital shock on the economy with the full summer water supply is a 5% decrease in real GDP. The simulation results show that the capital reduction

[6] We did not shock the capital invested in power generation. Without the High Aswan Dam, the capital invested in hydropower generation would have been invested in other types of power plants.

Table 7 – Risk premium as a function of risk aversion

P	EY	Y^{CE}	RP	% of 1997 GDP
3.0	255.1	250.8	4.25	1.7%
2.5	255.1	251.6	3.44	1.3%
2.0	255.1	252.5	2.60	1.0%
1.5	255.1	253.3	1.81	0.7%
1.0	255.1	254.0	1.12	0.4%
0.9	255.1	254.1	0.99	0.4%
0.7	255.1	254.3	0.75	0.3%
0.5	255.1	254.6	0.52	0.2%
0.3	255.1	254.8	0.30	0.1%
0.1	255.1	255.0	0.10	0.0%
0.0	255.1	255.1	0.00	0.0%

has it greatest impact at high Nile flows where less investment in the agricultural sector means a diminished capacity to use the Nile flows. For lower Nile flows, the impact on GDP impacts decrease; at extremely low flow, the impact actually becomes positive as the economy reallocates labor to more productive sectors than agriculture. Fig. 7 shows the relationship between the flow of the Nile and real GDP, shocking both water supply and capital stock. Table 6 summarizes the results for all simulations. Table 6 shows that the difference in expected values of real GDP over the 72 simulations with and without the capital shock to be EGP 1.1 billion or roughly 0.4% of 1997 GDP.

6. The risk premium of the High Aswan Dam

Finally, we computed the risk premium for the various scenarios described above. Following Kolstad (2004), the certainty equivalent income Y^{CE} is implicitly defined as the solution to $U(Y^{CE})=EU(Y)$, where U is utility and E is the expectation operator. For a risk averse agent, $Y^{CE}<EY$, and the risk premium RP is defined as $RP=EY-Y^{CE}$. We specified utility in a form that allows a constant measure of relative risk aversion for any level of consumption; i.e.,

$$U(C)=\frac{C^{1-p}}{1-p} \tag{1}$$

Using the simulation results presented above, we are able to report expected income, certainty equivalent income, and the corresponding risk premium for a range of risk aversion coefficients.

Expected GDP is EGP 255.1 billion for 1997 without the Dam, and income and consumption are proportional in the static CGE model. Table 7 gives the resulting risk premiums for the High Aswan Dam as a function of a range of risk aversions coefficients from extremely risk averse to risk neutral. For the conventional assumption of logarithmic utility (i.e., a unity risk aversion), the risk premium amounts to 0.4% of GDP. This rapidly increases with increasing risk aversion (see Fig. 8).

While actual risk aversion for Egyptian decision maker has not been found, anecdotal evidence suggests that Egyptian farmers and decision makers are quite risk averse. This is evident in the building of the High Aswan Dam and the model results that showed higher expected agricultural production without the Dam. A risk premium amounts closer to 1% of GDP is expected.

7. Concluding remarks and research needs

The risk neutral static benefit of the High Aswan Dam is estimated here to be EGP 4.9 billion per year. Adding the dynamic effects of shocks to capital in agriculture and transport adds an additional EGP 1.1 billion per year. Taking uncertain flows absent the Dam into account, the risk premium (for the standard assumption of a logarithmic utility function) adds another EGP 1.1 billion per year. The total, EGP 7.1 billion, is 2.7% of GDP in 1997 with 15% attributed to modest

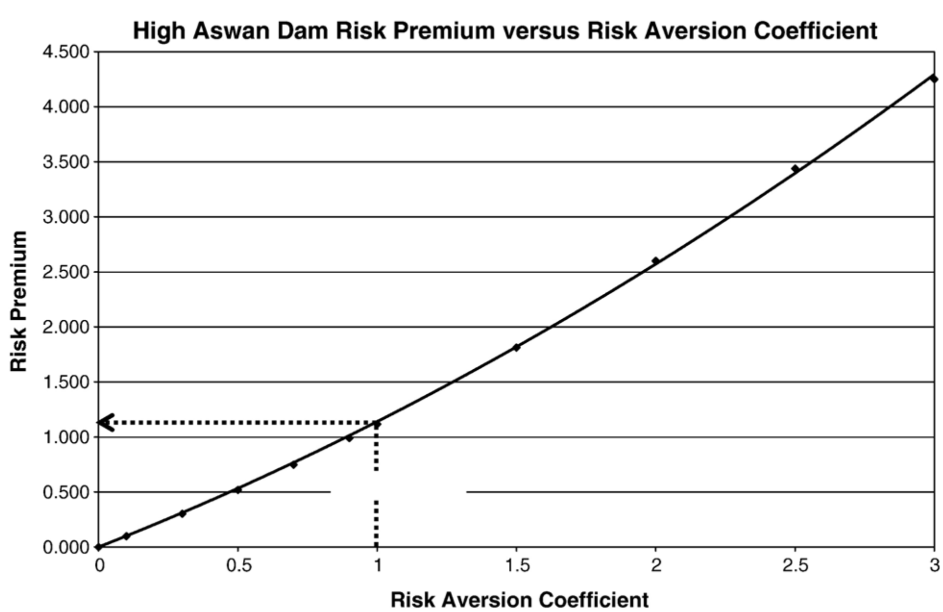

Fig. 8 – Risk premium versus risk aversion for High Aswan Dam.

risk aversion. However, with a very high risk aversion, the share of the risk premium goes up to 43%, and the total benefit of the High Aswan Dam to EGP 10.3 billion, or 4.0% of GDP.

Future research needs fall into four areas. We need to better determine the utility functions of Egyptian consumers and investment decision makers so that we can improve our estimates of their response to variability and risk; reduced risk premiums contribute a substantial fraction of the Dam's benefit. It follows that we need better modeling of the impacts of variability in Nile flow on all sectors of the economy with particular emphasis on the impact of (the threat of) floods on capital investment (the dynamic effect that accounts for a second significant portion of total benefits). In the same vein, we also need better understanding of the impact of large amounts of low cost hydroelectric power from the High Aswan Dam on capital investment within the non-agricultural sectors of the economy. The last two needs highlight the reliance of these results on risk premium and investment process derived from a static CGE; the analysis should be repeated with a dynamic model. All of this is deferred to future research.

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