THE VALUE OF THE HIGH ASWAN DAM TO THE EGYPTIAN ECONOMY

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10 June 2006

Working Paper FNU-111

Abstract

The High Aswan Dam converted a variable and uncertain flow of river water into a predictable and controllable flow. We use a computable general equilibrium model of the Egyptian economy to estimate the economic impact of the High Aswan Dam. We compare the 1997 economy as it was to the 1997 economy as it would have been for 72 historical, pre-dam water flows. The steady water flow increased transport productivity, while the seasonal shift in water supply allowed for a shift towards more valuable summer crops. These static effects are worth LE 4.9 billion. Investments in transport and agriculture increased as a consequence. Assuming that Egypt is a small open economy, this is worth another LE 1.1 billion. The risk premium on the reduced variability is estimated to be LE 1.1 billion for a modest risk aversion, and perhaps LE 4.4 billion for a high risk aversion. The total gain of LE 7.1 billion equals 2.7% of GDP.

Key words

Egypt, High Aswan Dam, computable general equilibrium model, risk premium, water supply

JEL Classification

C68, O13, Q25

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 variability can be manipulated to deliver supplies of water that match the optimal intra-annual demand pattern. The question to be addressed here is "What is the value to the Egyptian economy of the resulting reduction in uncertainty (reduced risk in the supply of water)?" Put another way, "What is the economic value of water security to the Egyptian people?"

Risk averse consumers frequently try to maximize expected utility so that they can incorporate risk explicitly into their investment and consumption decisions. This is why they buy insurance. The key to see why is to notice that these consumers can compute a "certainty equivalent" outcome for which their utilities will equal the expected utility over a random set of plausible outcomes and that this certainty equivalent outcome is less than the expected value of those plausible outcomes. Thus, they would be willing to pay a little to avoid the risk.

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. Our primary analytical tool is a Computable General Equilibrium (CGE) model of Egypt. The model is used to carry out comparative-static simulations of Egypt's economy with and without the Dam. The analysis covers the impact of the dam through the following channels: changes in the supplies of irrigated land and water; changes in the supplies of electric power; changes in yields and production technology (primarily changes in fertilizer use); and real costs associated with the investment relative to other investments (in flood control and hydropower) that would have been likely in its absence. In addition, the analysis will consider the implications of the fact that, without the dam, the performance of Egypt's economy in each year would have depended on highly variable flows in the Nile. The model is built around a 1996/97 Social Accounting Matrix (SAM) for Egypt. For our simulations, we draw on a wide range of additional information, most importantly historical data on Nile flows and assessments of various aspects of the costs and benefits analyses of the High Aswan Dam in the literature.

This analysis explores the main effects, both costs and benefits, of the dam in a typical year during its lifetime. We divide the effects into direct and indirect. The impact indicators include production, trade, as well as disaggregated household incomes and their distribution. A virtue of the relatively simple framework (compared to a fully dynamic model) is that it is relatively straightforward to implement. Our analysis provides a prototype that can be applied to other cases. The only requirement is to put together a database, the components of which are identified below.

We will proceed 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 the static results. The simulations are used to assess how Egypt's economy would have performed in 1996/97 without the dam and how the economy, with and without the Dam, would have been affected by year-to-year variations

Nile flows. Section 5 expands the analysis by including the dynamic effects as well. In Section 6, we compute the "risk premium" of the High Aswan Dam. Section 7 concludes.

2. Egypt and the High Aswan Dam

After the July 1952 Revolution, studies were carried out to construct the High Aswan Dam. The World Bank initially agreed to finance the huge project but later withdrew its consent. The nationalization of the Suez Canal generated the revenue to finance the project, with technical assistance from the Soviet Union.

On January 9, 1960 the foundation stone of the High Aswan Dam was laid. On January 15, 1971 a ceremony was held marking the completion of the High Dam. The total cost of its construction was LE 500 million. Fifty thousand engineers and workers took part in the implementation of this giant project. The High Aswan Dam is a rock-filled dam south of Aswan. It is 3600 meters long and pyramidal in shape. It is 980 meters wide at the base and 40 meters at the top. It is 111 meters high above the Nile floor and 196 meters above sea level.

Water is released via six tunnels, 14 meters in diameter. There are 12 units for hydraulic power generators. A great lake has been formed in front of the High Aswan Dam, Lake Nasser, with a storage capacity of 164 billion cubic meters, and a depth that reaches 182 meters. Lake Nasser is a large reservoir in the midst of the desert with a large surface area, which leads to enormous amounts of evaporation.

In 1959, Egypt and Sudan signed the Nile Waters Agreement, a bi-lateral agreement to allocate the water of the Nile potentially crossing the Egyptian-Sudanese border. The agreement assumed the availability and proposed allocations shown in Table 1.

Egypt is allowed to annually release 55.5 BCM. With the active storage of 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. Figure 1 shows the impact of High Aswan Dam on water supply availability to Egypt.

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 flows account for approximately 70 percent of Nile flow at Aswan and primarily come in the three months of August, September, and October; the source is the Blue Nile with its headwater in Ethiopia. Summer flow comes almost exclusively from the White Nile, which exits the Sudd wetlands in Southern Sudan after losing 50% of its volume to evapotranspiration by wetland vegetation.

The economic benefits of providing a highly reliable and non-flooding water supply to Egypt are:

- It has saved Egypt from devastating floods and the resulting loss of summer harvests, damage to infrastructure, and loss of life.

- The High Dam water has been used in reclaiming about 1.2 million feddans[1].
- Perennial irrigation of about 850 thousand feddans has replaced basin irrigation.
- Rice and sugar cane production has increased considerably.
- The High Dam turbines generate an average of 8 billion kilowatt/hour used in industry and the electrification of all towns and villages in Egypt.
- The High Dam has facilitated navigation up and down the Nile all the year round.

Table 2 shows the actual crop areas in 1995, 25 years after the High Aswan Dam compared with Pre-Dam area. It shows major increases in wheat, maize, rice and sugar cane areas, and a major decrease in the cotton area.[2] Figure 2 shows that the little water available in Egypt during the summer cropping season, 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 but more importantly look at 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. Notice in Figure 2 how the cropping pattern is almost completely out of phase with the natural seasonal pattern of Nile flow. This is only possible due to the within-year water storage provided by the dam.

3. Overview of CGE model

CGE models are solvable numerically and provide a full account of production, consumption and trade in the modeled 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.* (2003).

The CGE model follows the disaggregation of a SAM and explains all payments that are recorded in the SAM. It is written as a set of simultaneous equations, many of which are non-linear. There is no social planner. 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

[1] 1 Feddan is 4,000 m^2.
[2] 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.

the system as a whole but which are not necessarily considered by any individual actor. These "system constraints" 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. Figure 3 provides a simplified picture of the links between the major building blocks of the model. 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 (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.

The producers are assumed to maximize profits subject to prices and a nested technology in three levels. 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 distinguish four crops, which only differ in their water intensity, so that farmers can substitute away or towards more water-intensive production. Each activity produces one or more commodities and any commodity may be produced by more than one activity.

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 the 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.[3] We use a long-term closure, with endogenous wages and an exogenous rate of return on capital.

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[3] 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).

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 of the world (fixed in foreign currency), and from 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 user 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.

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 apply a set of historical data about the Nile flows to determine how the Egyptian economy would have fared without the dam. Figure 4 is a histogram of the 72 years of historic Nile flow used as input to the model. In all simulations, the "shock" is to reduce the supply of summer water, using historical data on summer water flows. In effect, the removal of the dam is assumed to force Egypt to use less water in the summer season, with an excess supply of water in the winter. See Figure 2. The shock is applied to agriculture, transport, tourism, and power generation.

In the simulations, the model is run 72 times—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 is ignored. So, the experiments we report underestimate the gains from the dam, or the losses associated with “removing” the dam.

Figure 5 shows the frequency distribution for real GDP. 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.

If the High Aswan Dam would not have been there, agriculture gains (especially summer crops with high value) and the burden of the shocks falls on the non-agriculture sectors, with declines in power, transportation, and tourism. 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 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. However, the gain in agriculture is 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 between the with and without High Aswan Dam simulations is 4.9 LE Billion. This amounts to 2% of 1997 GDP. Overall, the dam generates significant gains.

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

*Above, we compute the static economic effects of the High Aswan Dam, that is, we shocked water supp*ly only. Water only affects the productivity of certain sectors. However, one might argue that, if the High Aswan Dam increased the productivity in a sector and at the same time reduced the variability of its production, then more would be invested in that sector. Therefore, we run a second set of simulations, which are identical to those above, but we shock capital as well. Because we use the small-country assumption of a fixed interest rate, capital is only shocked in those sectors that are directly affected by water supply.

Hansen (1991) shows 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%. If we interpret as caused by the construction of the High Aswan Dam, and proportionally extrapolate this from 1971, the completion of the Dam, to 1997, our calibration year, we find that invested capital in agriculture would be about 25% lower, and 50% for transport.[4]

The impact of the negative capital shock on the economy with the full summer water supply is a 5% decrease in real GDP. The simulation results show that shock has it greatest impact at high Nile flows where reduced capital in the agricultural sector means less ability of the agriculture 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. Figure 6 shows the relationship between Nile flow and impact of the shock on real GDP. 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 LE 1.1 billion. This amounts to 0.4% of 1997 GDP.

6. The risk premium of the High Aswan Dam

We compute the risk premium following Kolstad (2004). The certainty equivalent income Y^{CE} is implicitly defined as $U(Y^{CE}) = \mathrm{E}U$, where U is utility and E is the expectation operator. For a risk averse agent, $Y^{CE} < \mathrm{E}Y$. The risk premium RP is defined as $RP = \mathrm{E}Y - Y^{CE}$.

We specify utility to have a constant relative risk aversion:

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

Using the results from set of model simulations presented we are able to determine expected income, certainty equivalent, and thus the risk premium for a range of risk aversion coefficients.

The expected GDP is LE 255.1 billion. As we use a static CGE, income and consumption are proportional to each other. 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. Figure 7 plots the Table 7 data.

7. Conclusion

The risk neutral benefit of the High Aswan Dam is estimated at LE 4.9 billion. The impact of a capital shock in agriculture and transport is LE 1.1 billion. The risk premium (for the standard assumption of a logarithmic utility function) is LE 1.1 billion. LE 7.1 billion is 2.7% of GDP in 1997, 15% of which is due to 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 LE 10.3 billion, or 4.0% of GDP.

[4] 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.

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. Related to this, we need to better model the impact of Nile flow variability on all sectors of the economy; especially the impact of (the threat of) floods on capital investment. We also need to better understand 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. Furthermore, we computed risk premium and investment using a static CGE – the analysis will need to be repeated with a dynamic model. All this is deferred to future research.

Acknowledgements

The authors wish to thank Sherman Robinson, Hans Lofgren, and Moataz El-Said for their efforts on the basic Egyptian GCE Model and their collaboration on the variable Nile flow version and graciousness in sharing all results. Financial support by the Hamburg University Innovation Fund is gratefully acknowledged. All errors or omissions are the responsibility of the authors.

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

Average Annual Nile Flow	84.0 10^9 m^3
Reservoir Losses Due to Evaporation and Seepage	-10.0 10^9 m^3
Net Water Availability per Annum	74.0 10^9 m^3
Allotment to the Sudan	18.5 10^9 m^3
Allotment to Egypt	55.5 10^9 m^3
Total Water Usage per Annum	74.0 10^9 m^3

Table 2. Cropped Area

	1960	1995
Wheat	1,387	1,829
Maize	1,727	1,906
Millet	469	346
Rice	799	1,276
Cotton	1,751	884
Sugar Cane	122	274
Total	6,255	6,515

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	1,816.38	1,829,232	3.3	5.1
Legumes	1,461.37	323,700	0.5	0.7
Long Berseem	2,538.18	1,668,846	4.2	6.5
Short Berseem	903.47	642,643	0.6	0.9
Winter vegetables	1,489.10	508,040	0.8	1.2
Other Winter	1,286.65	75,429	0.1	0.1
Perennial-winter	2,030.51	794,032	1.6	2.5
Total Winter		5,841,922	11.1	17.0
Summer crops				
Cotton	3,025.81	884,310	2.7	4.1
Rice	4,691.40	1,276,295	6.0	9.2
Maize+Sorghum	2,525.84	2,252,043	5.7	8.8
Summer Veg	1,939.89	558,549	1.1	1.7
Other Summer	2,473.08	286,106	0.7	1.1
Perennial-summer	3,770.94	794,032	3.0	4.6
Total Summer		5,257,303	19.1	29.4
Total annual		11,099,225	30.2	46.5

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

Table 5: Expected Annual Net Benefits of HAD from CGE Analysis 1997

Expected REAL GDP with HAD	**260.0** LE billion(1997)
Expected REAL GDP without HAD	**255.1** LE billion(1997)
Net Expected REAL GDP from HAD	**4.9** LE billion(1997)

Table 6: Expected Annual Net Benefits with and without Capital Shock from CGE Analysis 1997

Expected REAL GDP with Full Capital	**255.1** LE billion(1997)
Expected REAL GDP with Capital Shock	**254.0** LE billion(1997)
Net Expected REAL GDP from Capital Shock	**1.1** LE billion(1997)

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%

Figure 1. Time Series of Nile Flow at Aswan and Impact of High Aswan Dam

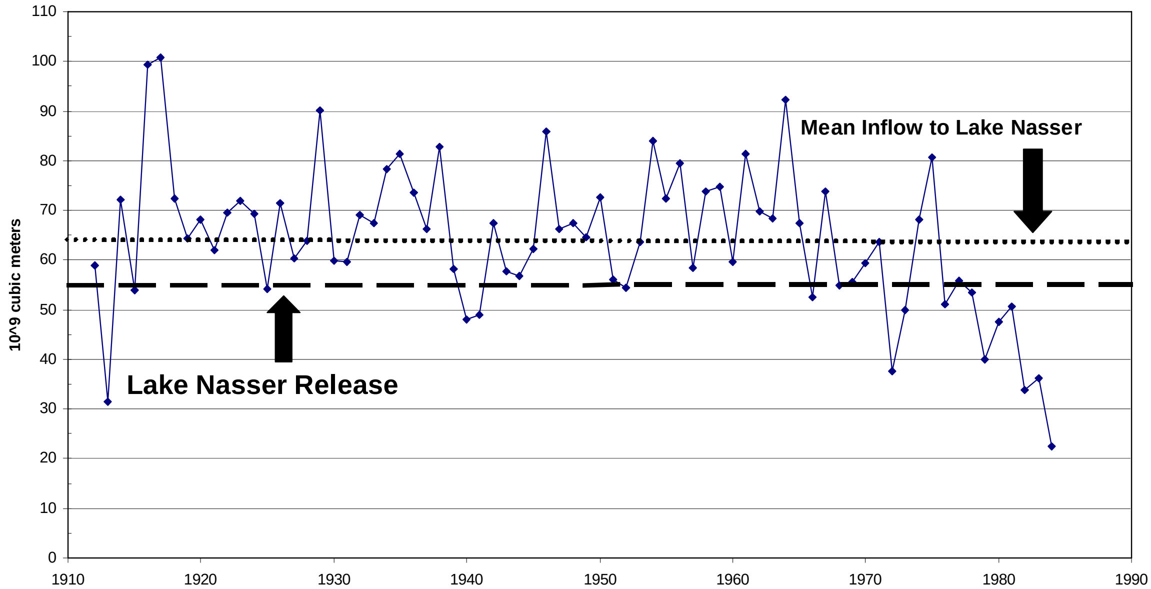


Figure 2
Nile Flow and Growing Seasons

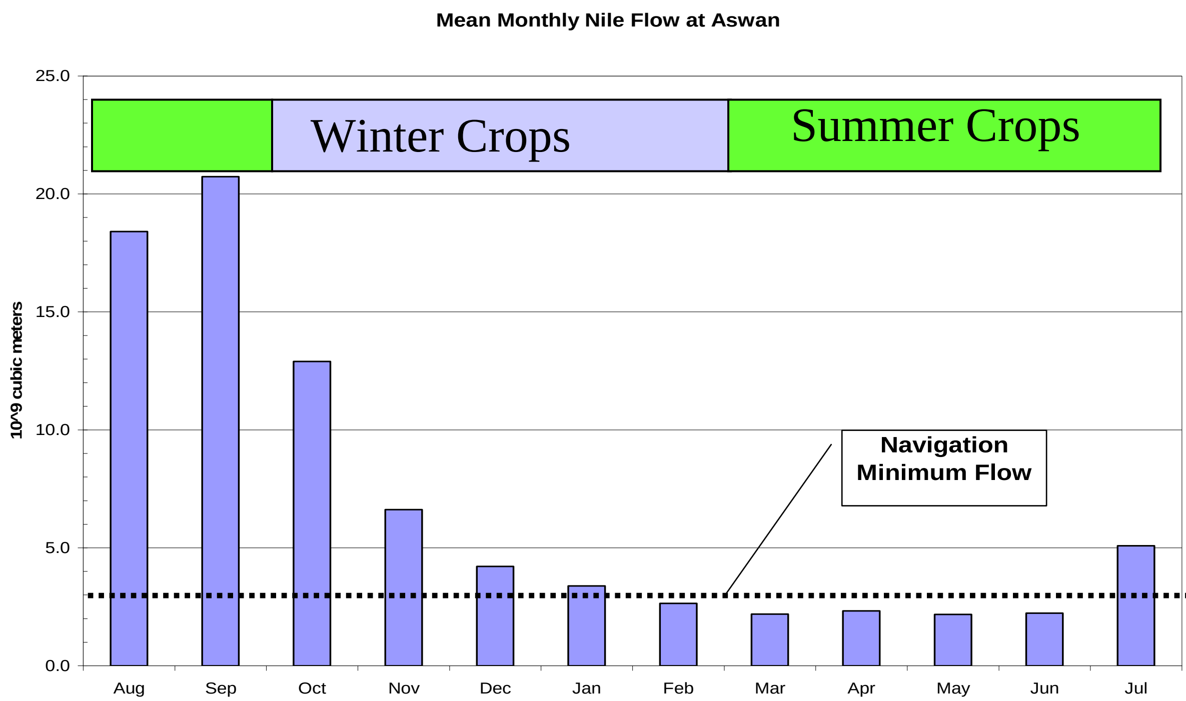


Figure 3: Structure of payment flows in the Standard CGE model.

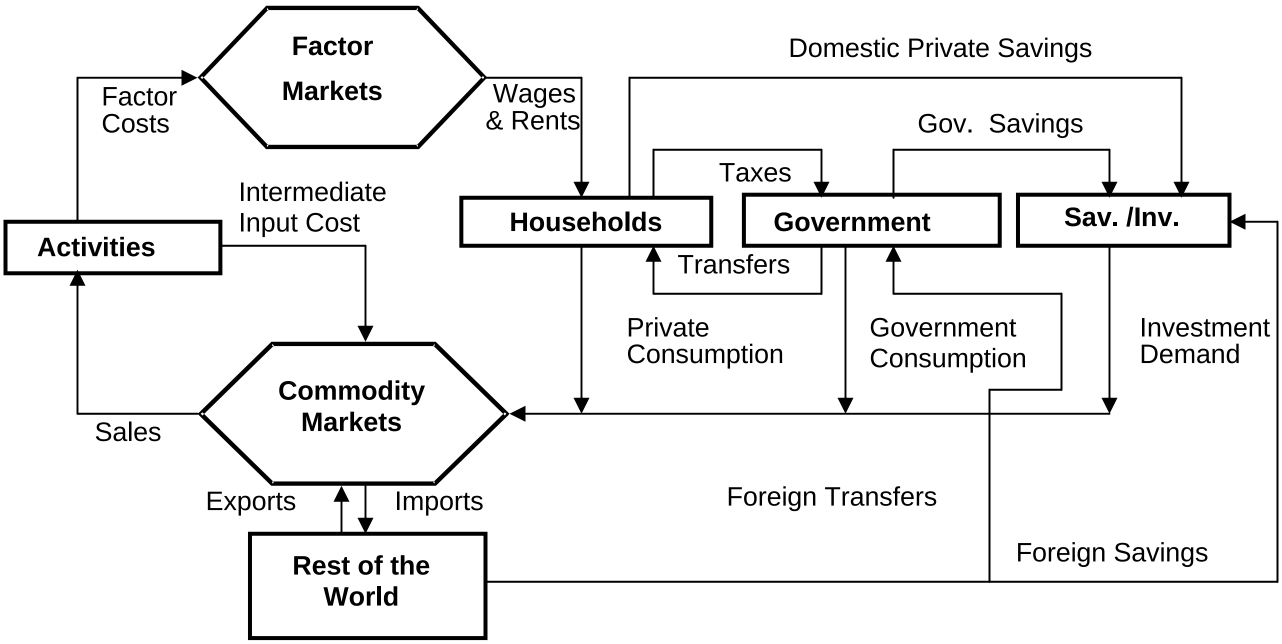


Figure 4. Histogram of Annual Nile Flow at Aswan

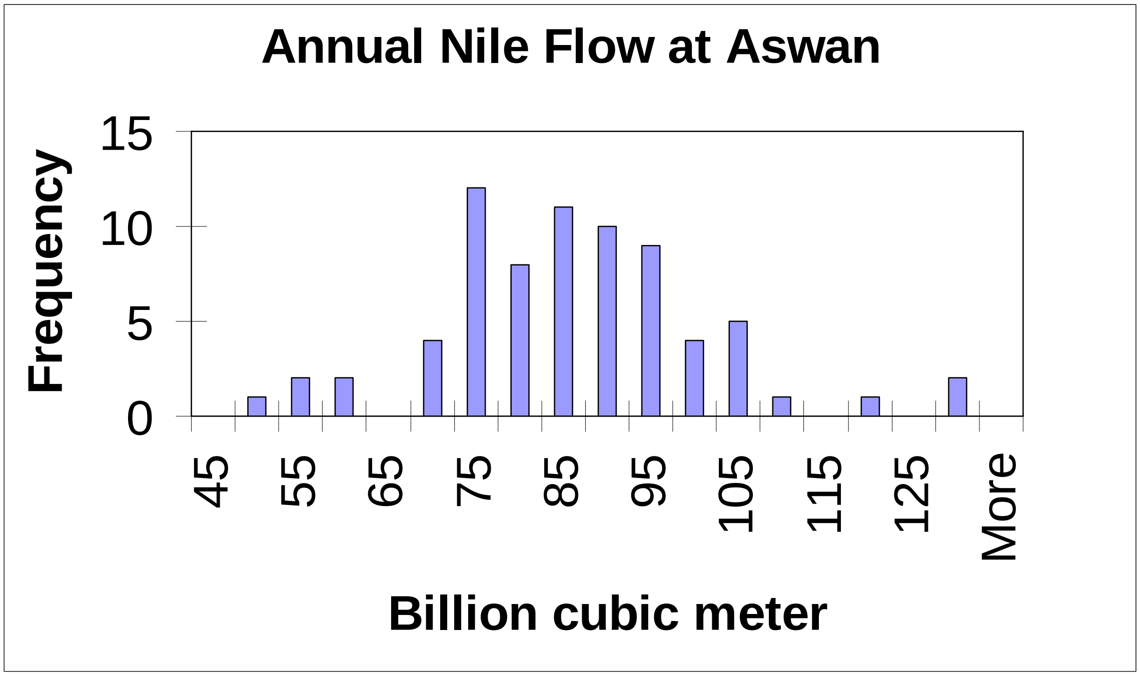


Figure 5. Histogram of Modeled GDP

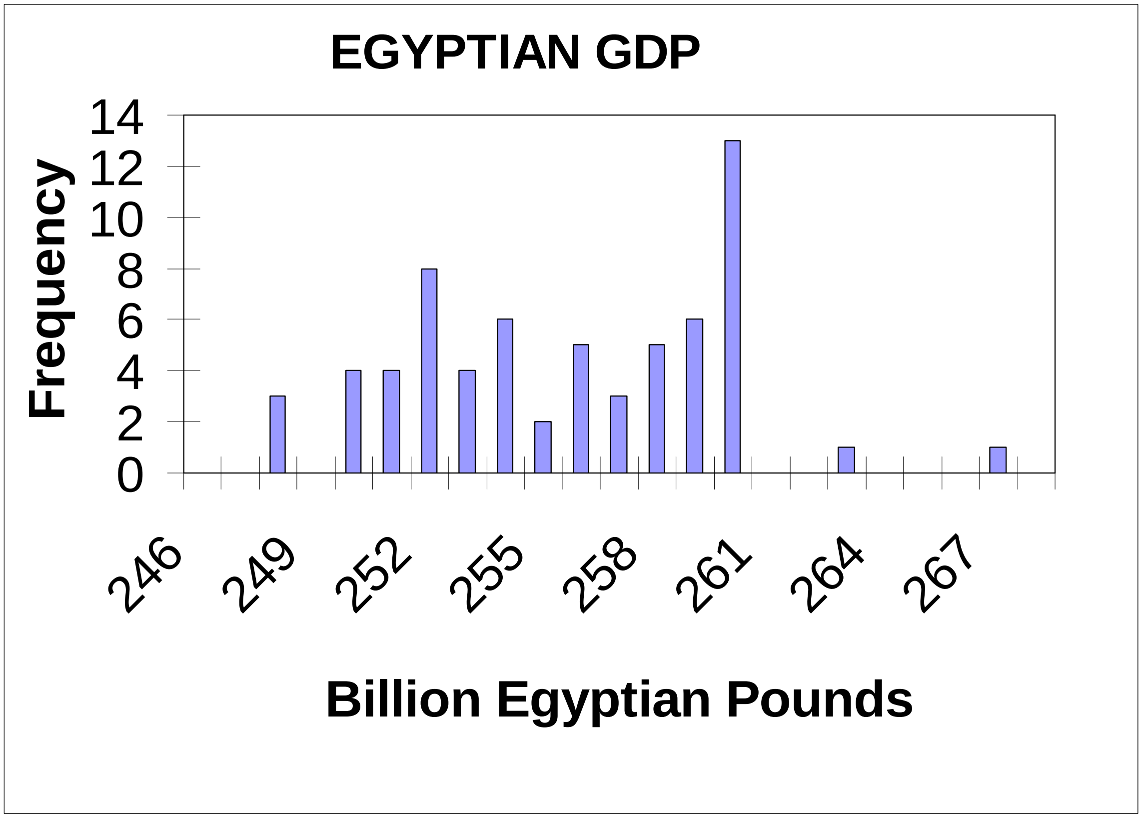


Figure 6. Impact of Capital Shock as a function of Nile Water Supplyact of m

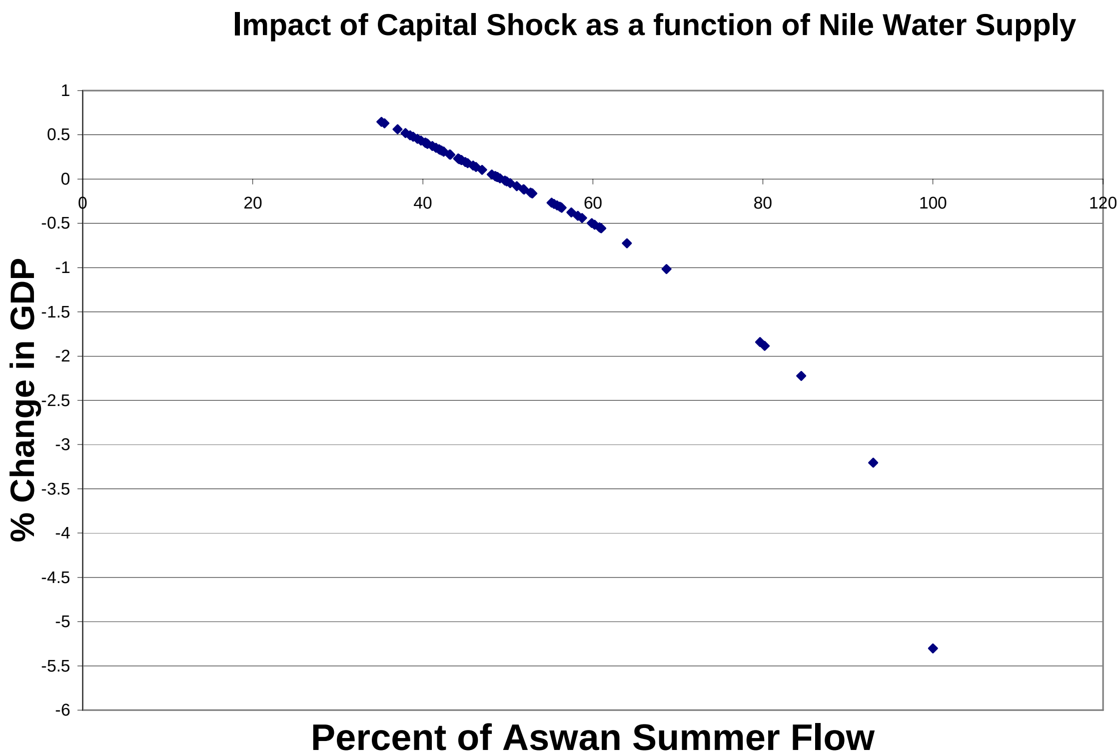
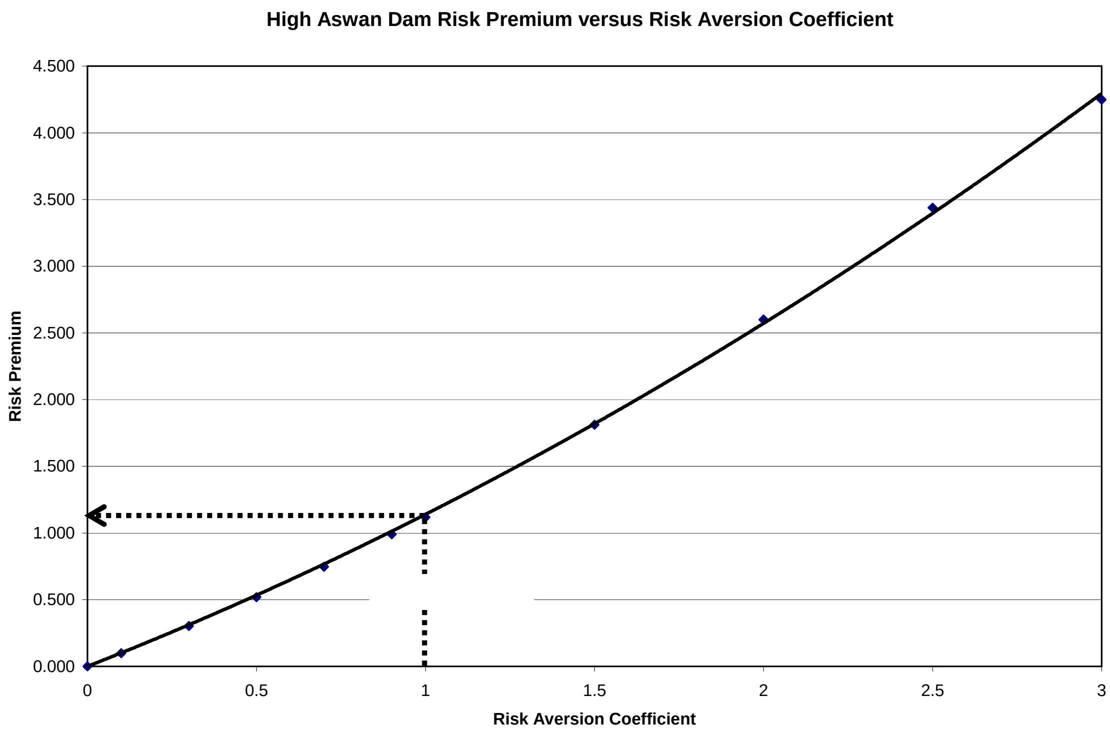


Figure 7. Risk Premium versus Risk Aversion for High Aswan Dam



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Strzepek, K.M., G.W. Yohe, R.S.J. Tol and M. Rosegrant (2006), *The Value of the High Aswan Dam to the Egyptian Economy*, **FNU-111** (submitted).

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