Green paradoxes and red herrings

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Introduction

Market power in fossil sector

Market power in fossil sector

The majority of fossil fuels must remain in the ground.

In first best the most valuable (oil and gas) and least polluting (oil and gas) should be used (McGlade and Ekins, 2015) .

Failure to price carbon is not the only problem.

If we fix carbon pricing but not the other problems, no first-best. And maybe even ‘paradoxical’ effects like higher emissions.

We add market power in the oil sector.

Compare to ‘green paradox’ with only one market failure. Here a Pigovian tax delivers first best, but other tax paths will not, and may lead to paradoxical effects. . .

Market power in fossil sector

If the only fossil fuel were a homogenous stock of oil then market power in the oil sector would be unambiguously emissions-reducing in laissez faire.

But when the most accessible oil reserves are controlled by a cartel, the resultant higher prices may let in other fossil fuels, which are intrinsically less accessible or more polluting.

We build a simple model in which competitive coal and renewable energy suppliers compete with an oil monopolist in electricity and vehicle power.

Given naive policy—a Pigovian tax alone—the result may be not just reduced overall welfare compared to first-best, but also higher long-run emissions.

Market power in fossil sector

Is market power significant?

- For the lowest-cost producers the oil price is well above cost.
- Other (higher-cost) producers extract and sell approximately at cost.
- The oil price has no clear growth trend (Hotelling).

These observations:

- Are wildly at odds with standard ‘Hotelling/Green Paradox’ model of zero extraction costs and perfect markets.
- Can (only?) be explained by the presence of market power in the sector. See e.g. Hassler/Krusell/Olovsson (2010).

Market power in fossil sector

Existing literature: Hassler et al (2010) and de Sa and Daubanes (2016).

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Hassler et al, two-period two-country model with a single fossil input controlled by one of the two countries. Later they add a third country —denoted 'Norway'—which extracts oil despite higher costs.

They analyse laissez faire, and compare to an economy with perfect competition, and one with emissions taxes.

> [I]t is worthwhile taking monopoly power seriously in any analysis of the global energy market. Quantitative explorations are urgently needed.

Market power in fossil sector

Existing literature: Hassler et al (2010) and de Sa and Daubanes (2016).

De Sa and Daubanes set up a monopoly–fringe model in which the oil monopolist sets the price at the limit to exclude the fringe, and test the effects of alternative policies.

There is no social utility function or regulatory optimization problem, hence they do not consider optimal policy.

Various results, e.g. that subsidies to the backstop will increase oil extraction, since the limit price is reduced, increasing oil demand.

Market power in fossil sector

This paper:

- Dynamic supply of oil;
- Competition with coal and renewables;
- Welfare analysis;
- Theoretical results and numerical simulations.

Results:

- Pigovian tax on coal;
- Sub-pigovian tax on oil, which approaches Pigovian level over time;
- Naive pigovian tax on oil leads to higher long-run emission, because more coal used.

To do:

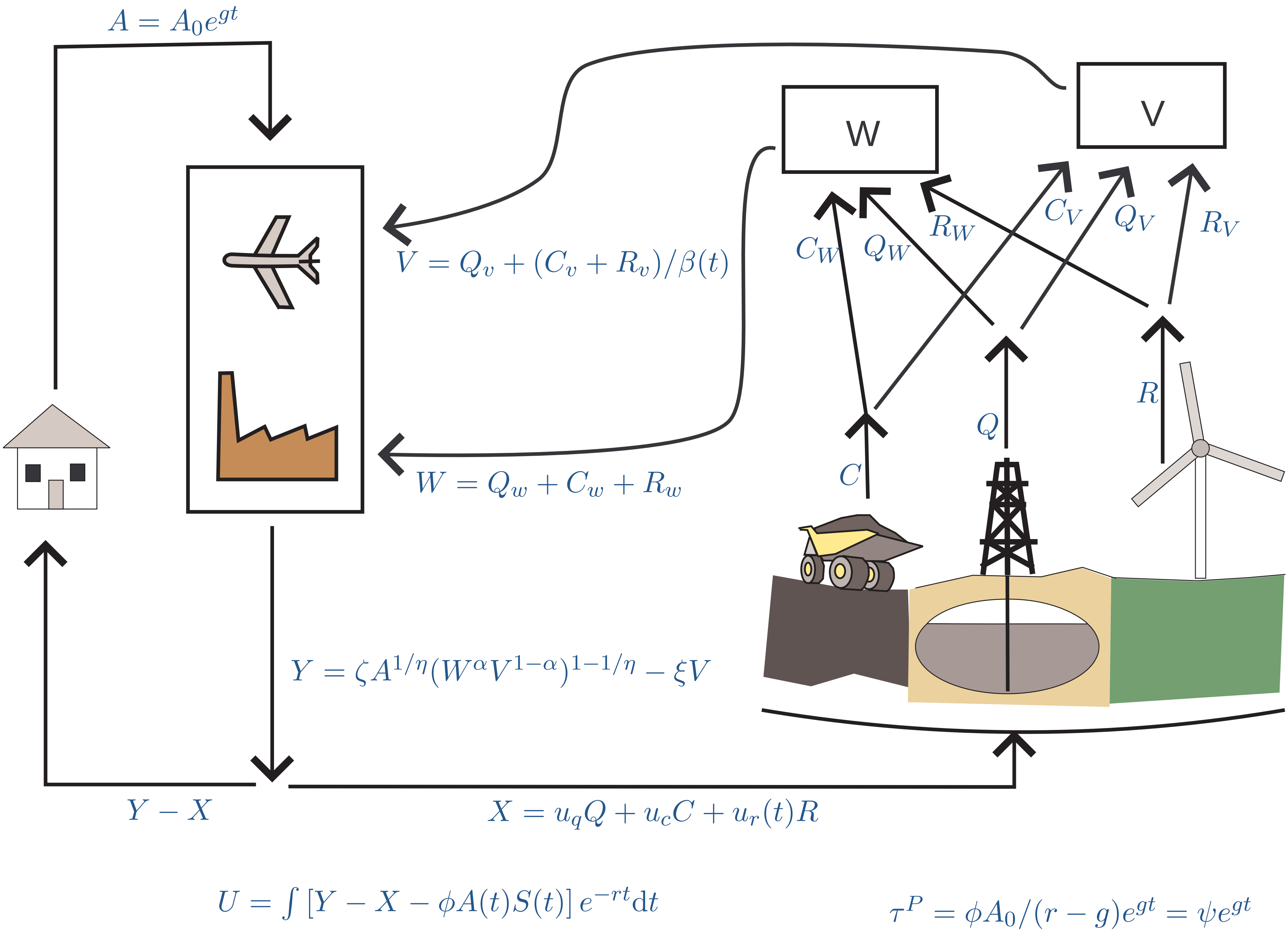
- Oiligopoly model.

Green paradoxes and red herrings


You're just going to keep looking under this light?
Well, I literally can't see anything in the dark, so yeah.
@redpenblackpen


What the f***'s going on?

The model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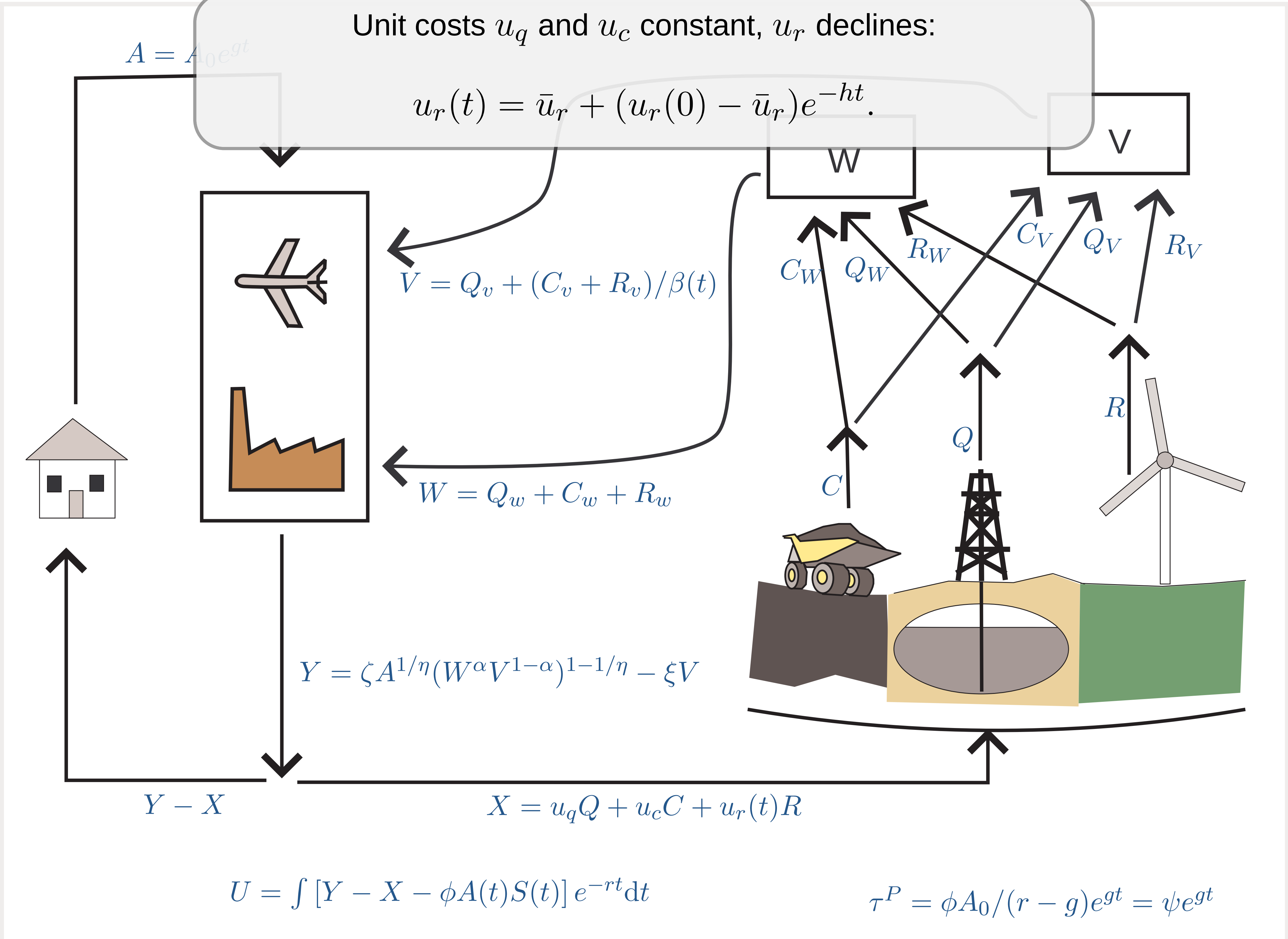
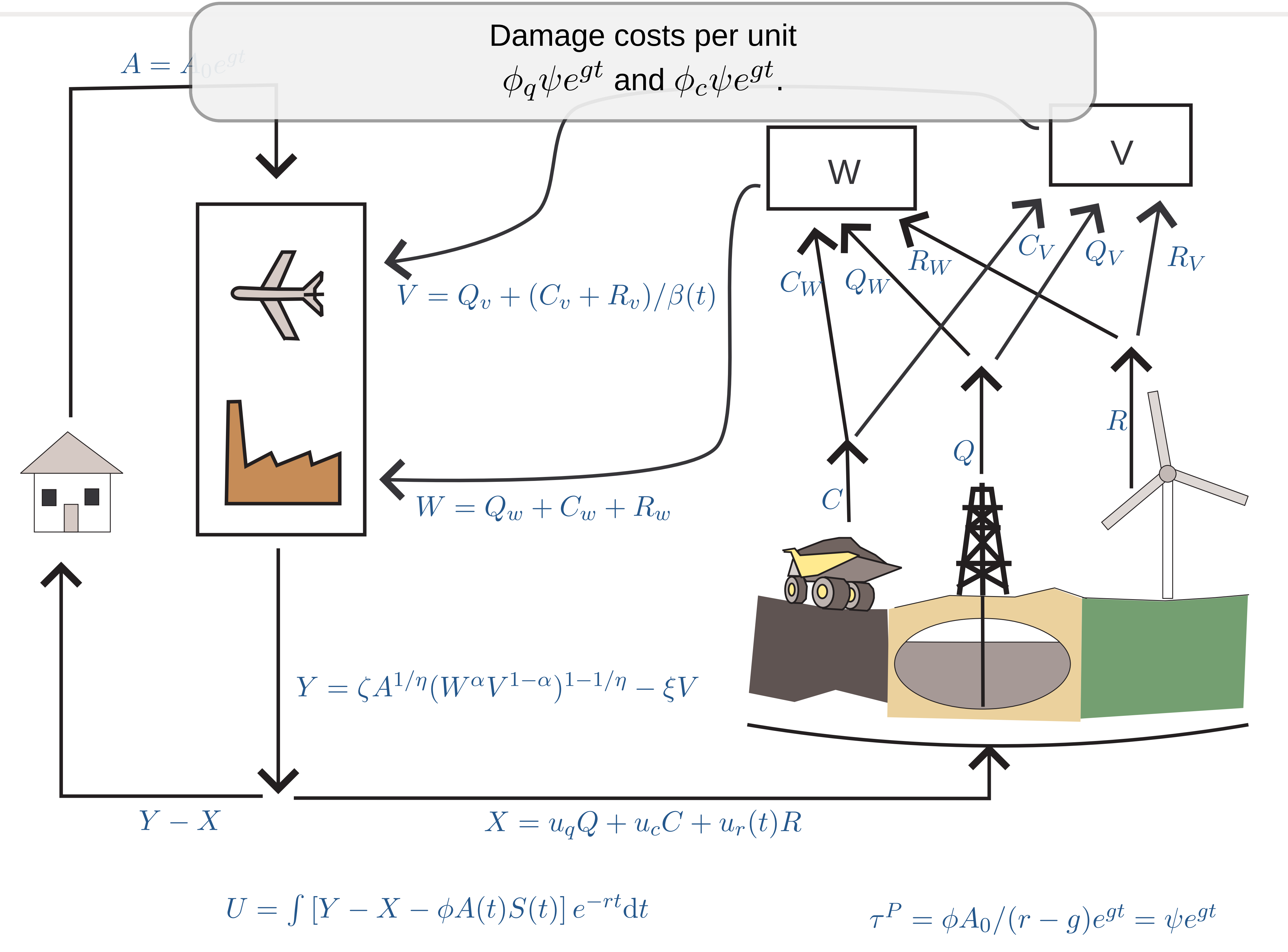
$U = \int [Y - X - \phi A(t) S(t)]\, e^{-rt} \mathrm{d}t$
$\tau^P = \phi A_0/(r-g) e^{gt} = \psi e^{gt}$

Unit costs u_q and u_c constant, u_r declines:

$$u_r(t) = \bar{u}_r + (u_r(0) - \bar{u}_r)e^{-ht}.$$




Damage costs per unit
$\phi_q \psi e^{gt}$ and $\phi_c \psi e^{gt}$.
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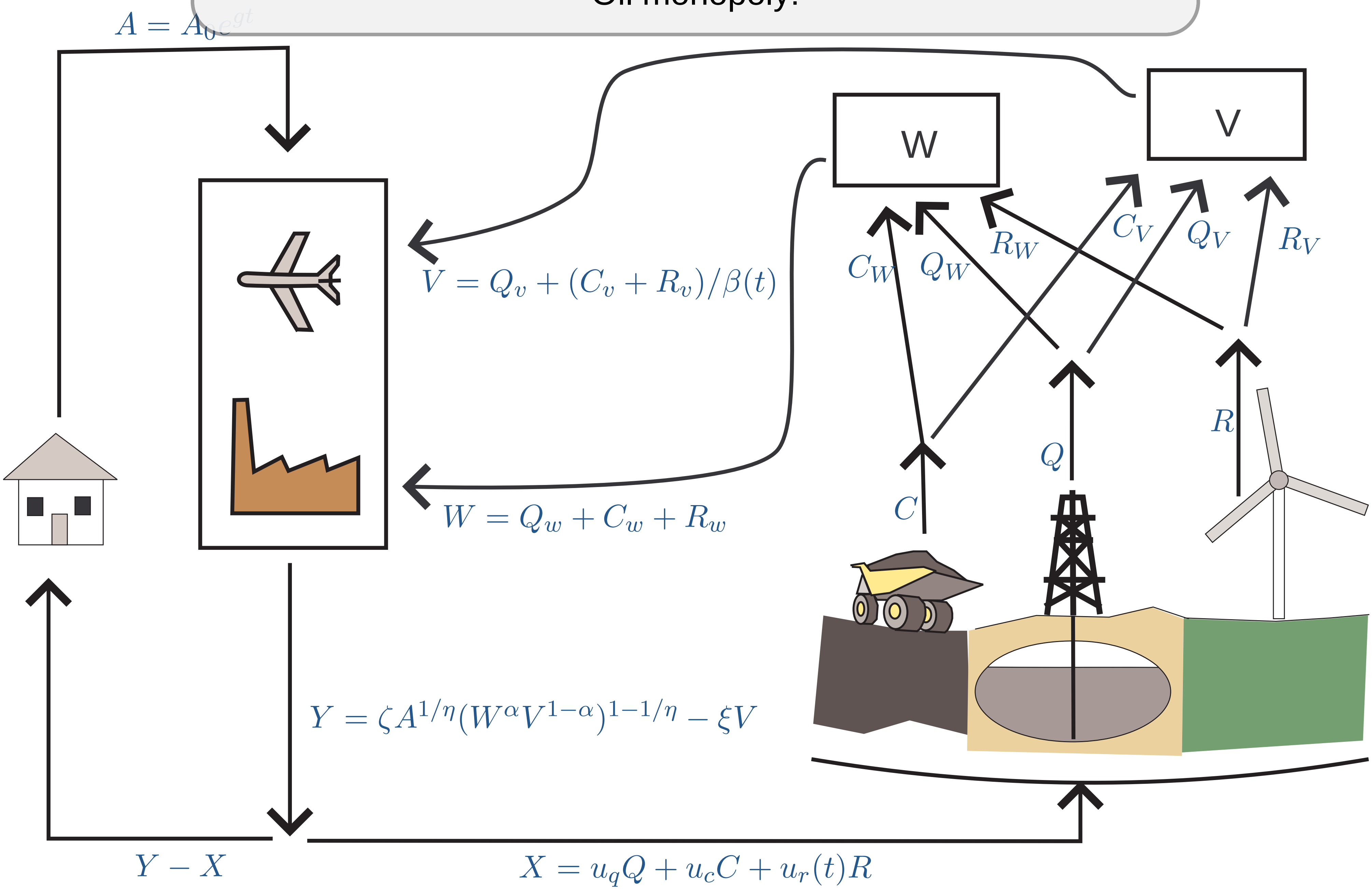
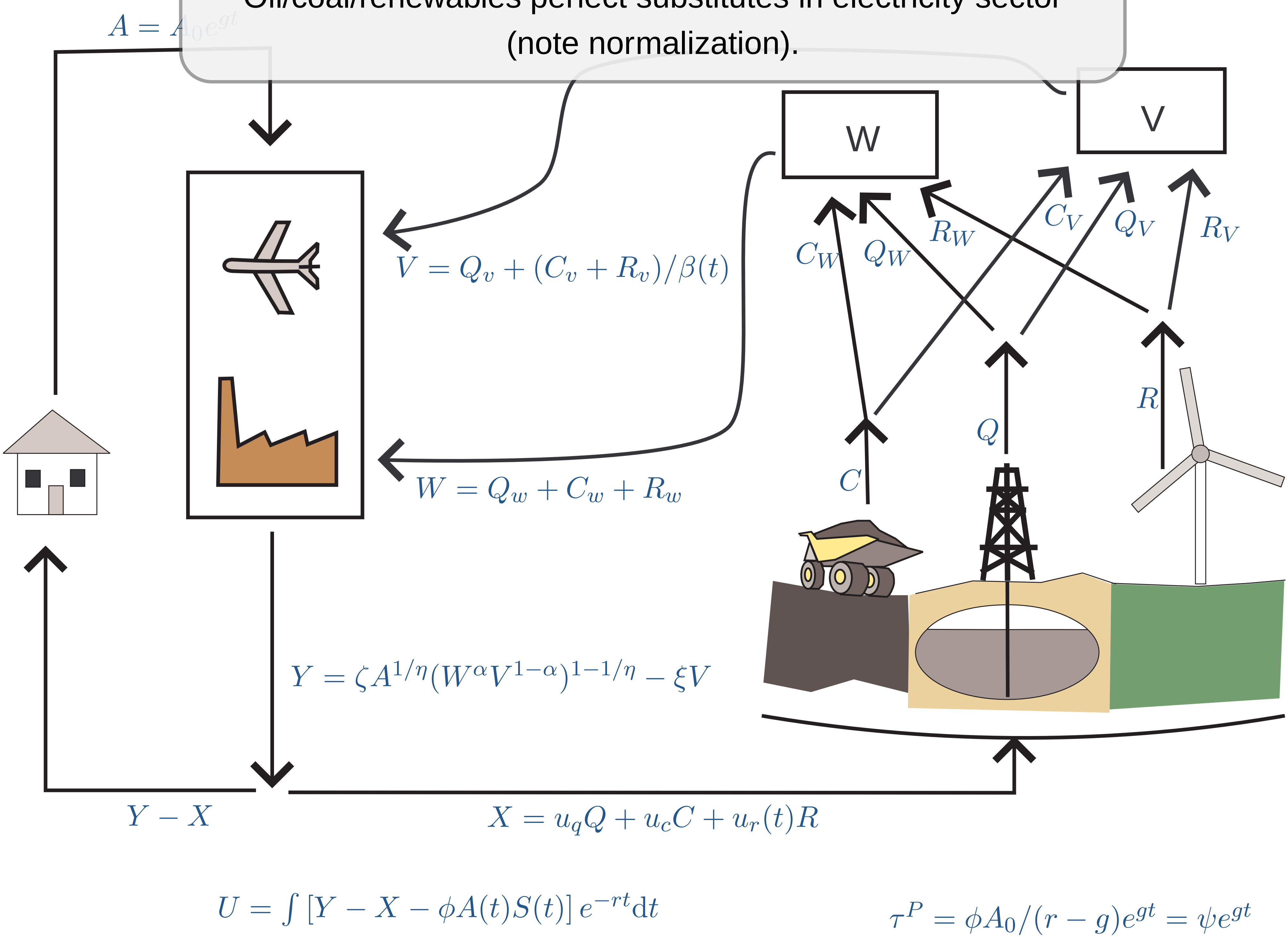
Oil monopoly!



$$U = \int \left[Y - X - \phi A(t) S(t)\right] e^{-rt} \mathrm{d}t$$

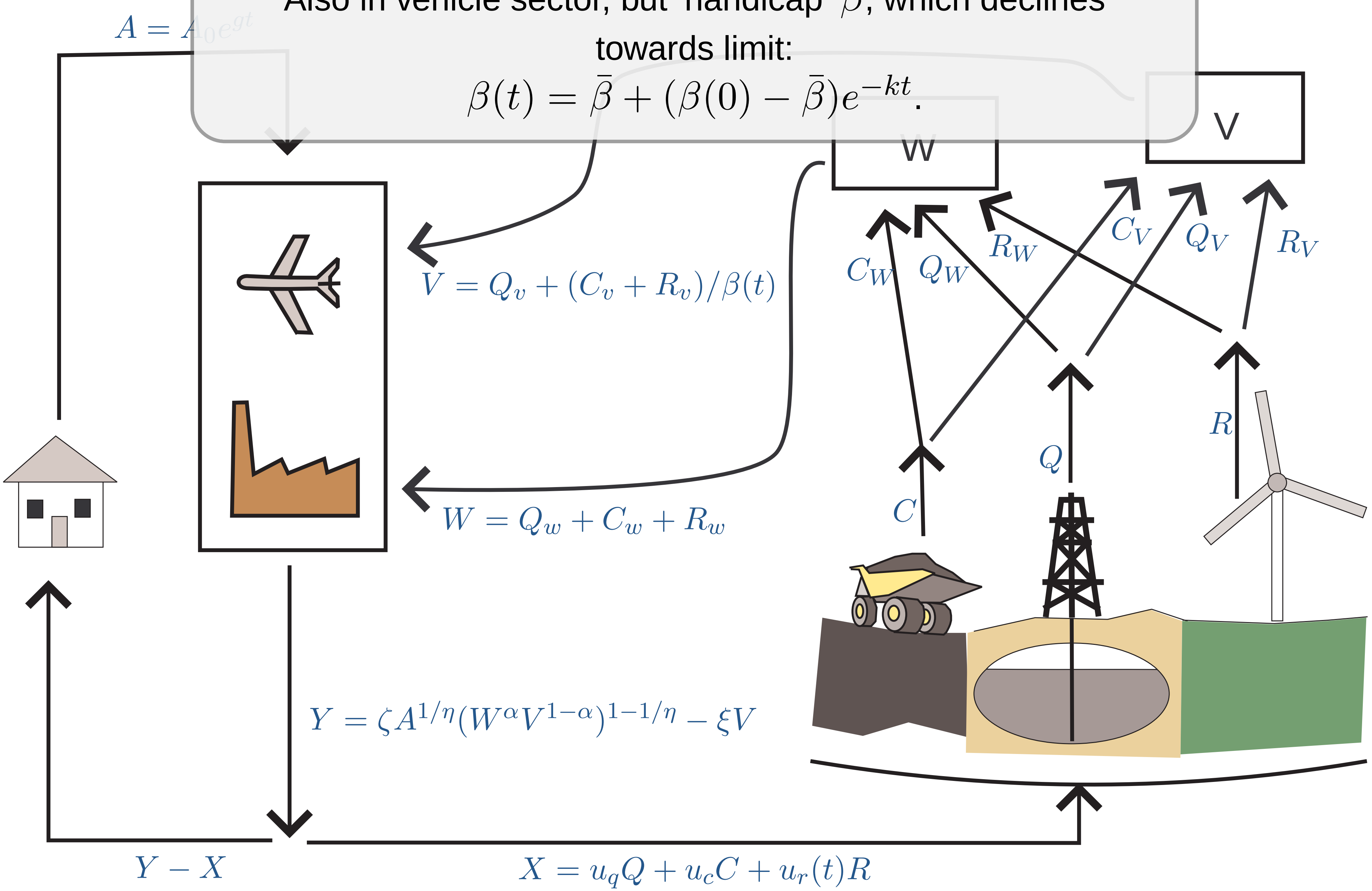
$$\tau^P = \phi A_0/(r-g) e^{gt} = \psi e^{gt}$$

Oil/coal/renewables perfect substitutes in electricity sector (note normalization).



Also in vehicle sector, but ‘handicap’ β, which declines towards limit:

$$\beta(t) = \bar{\beta} + (\beta(0) - \bar{\beta})e^{-kt}.$$



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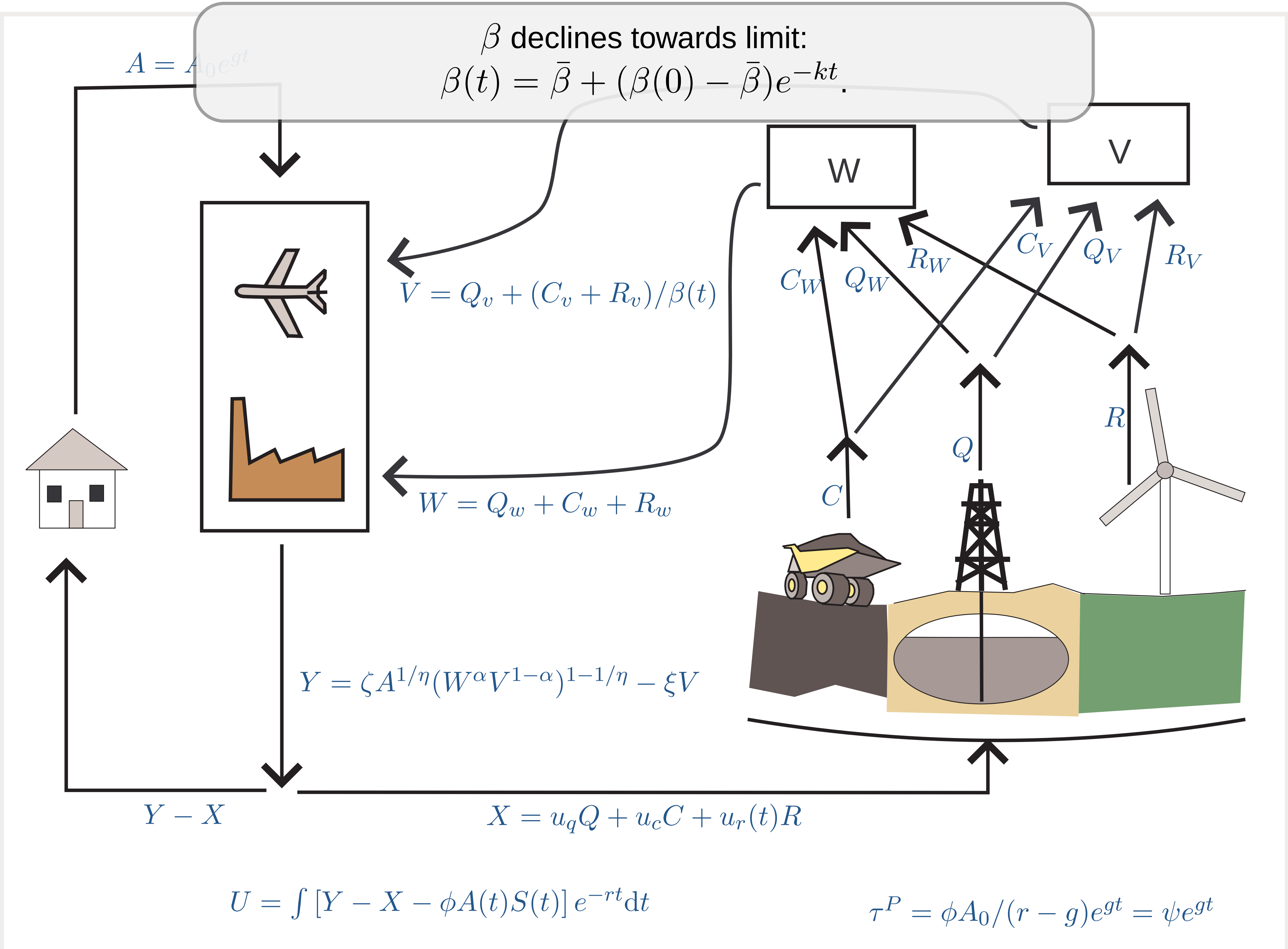

β declines towards limit:
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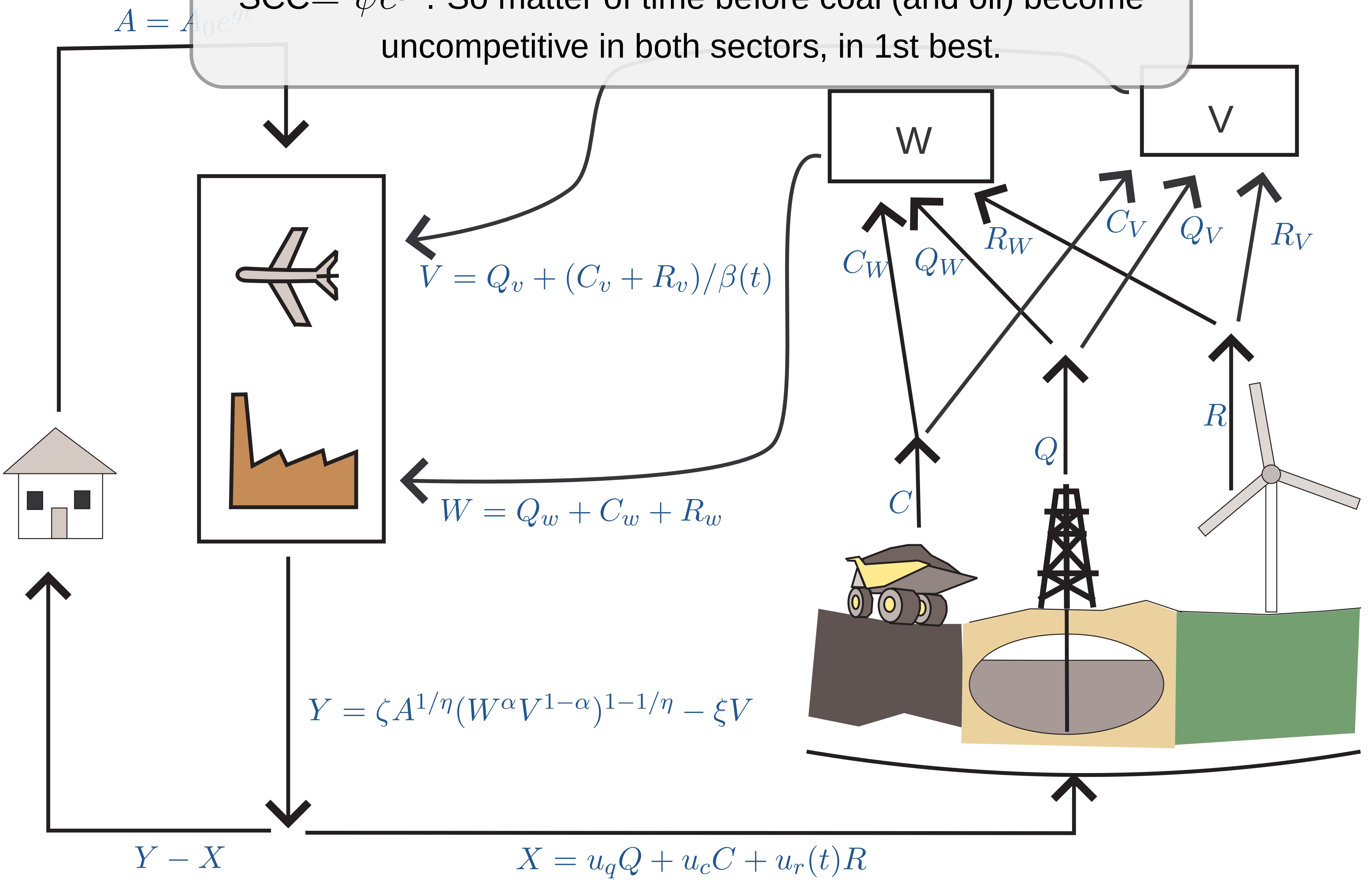
SCC= ψe^{gt}. So matter of time before coal (and oil) become uncompetitive in both sectors, in 1st best.



$U = \int [Y - X - \phi A(t) S(t)]\, e^{-rt} \mathrm{d}t$

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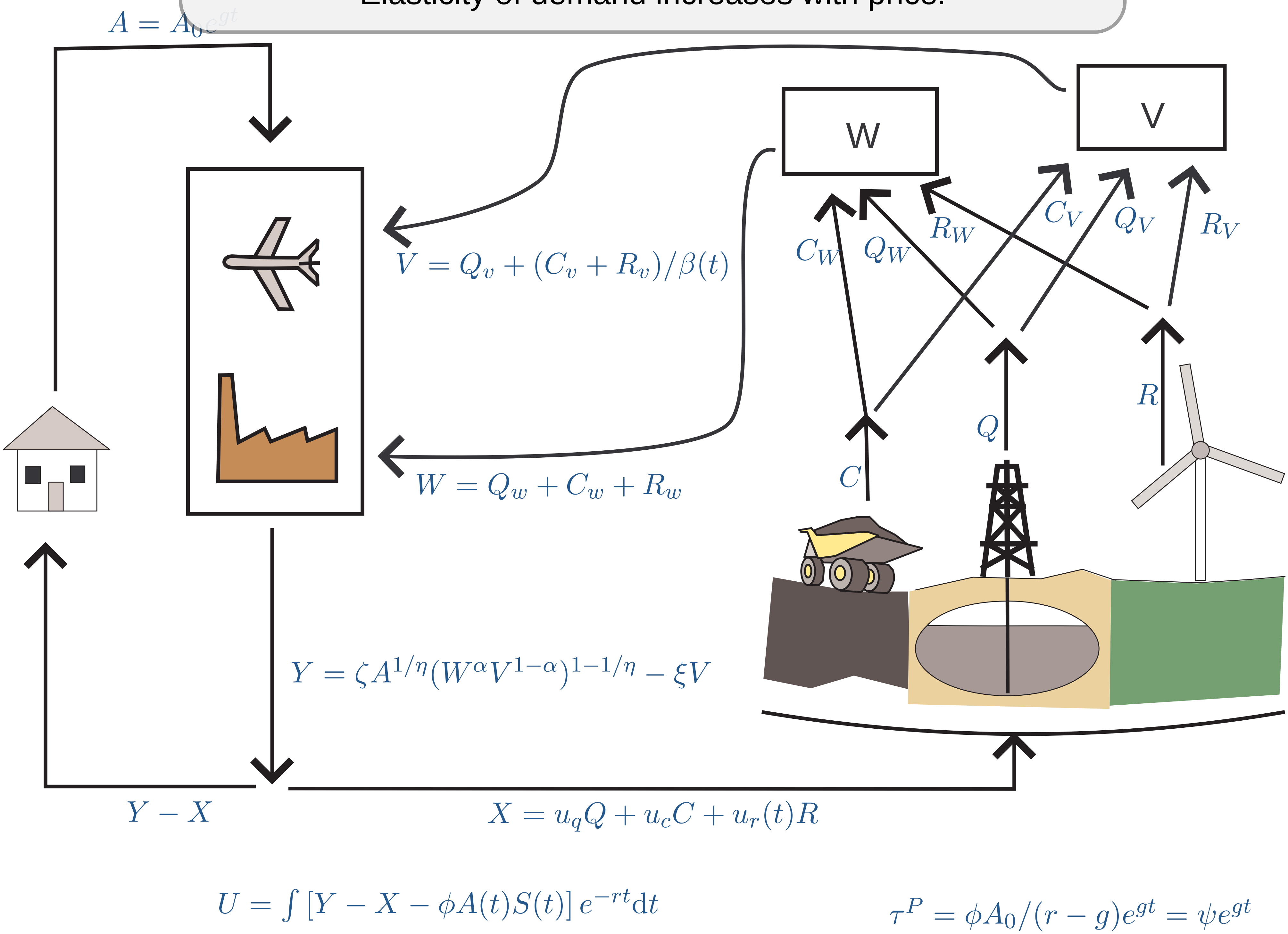
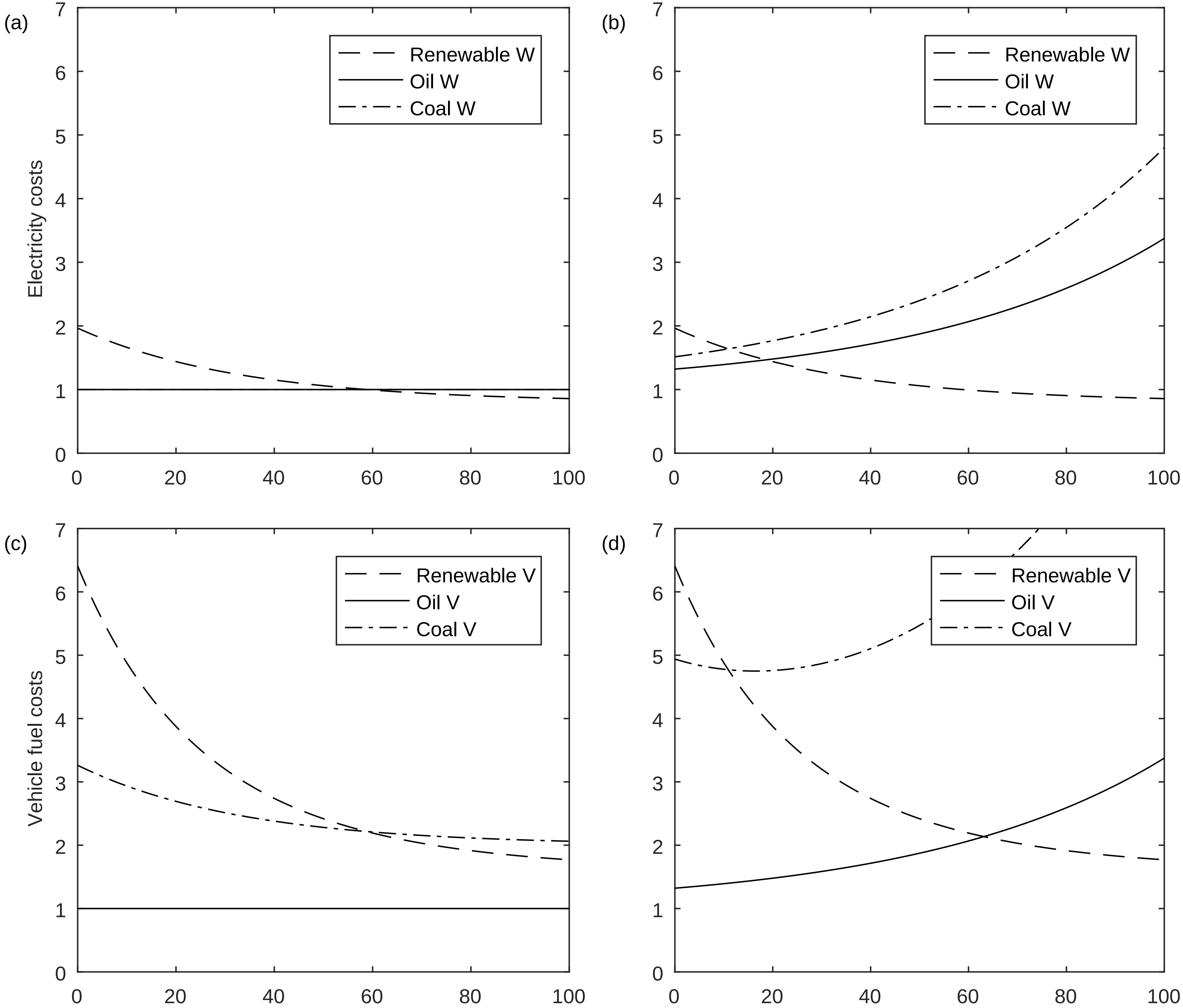
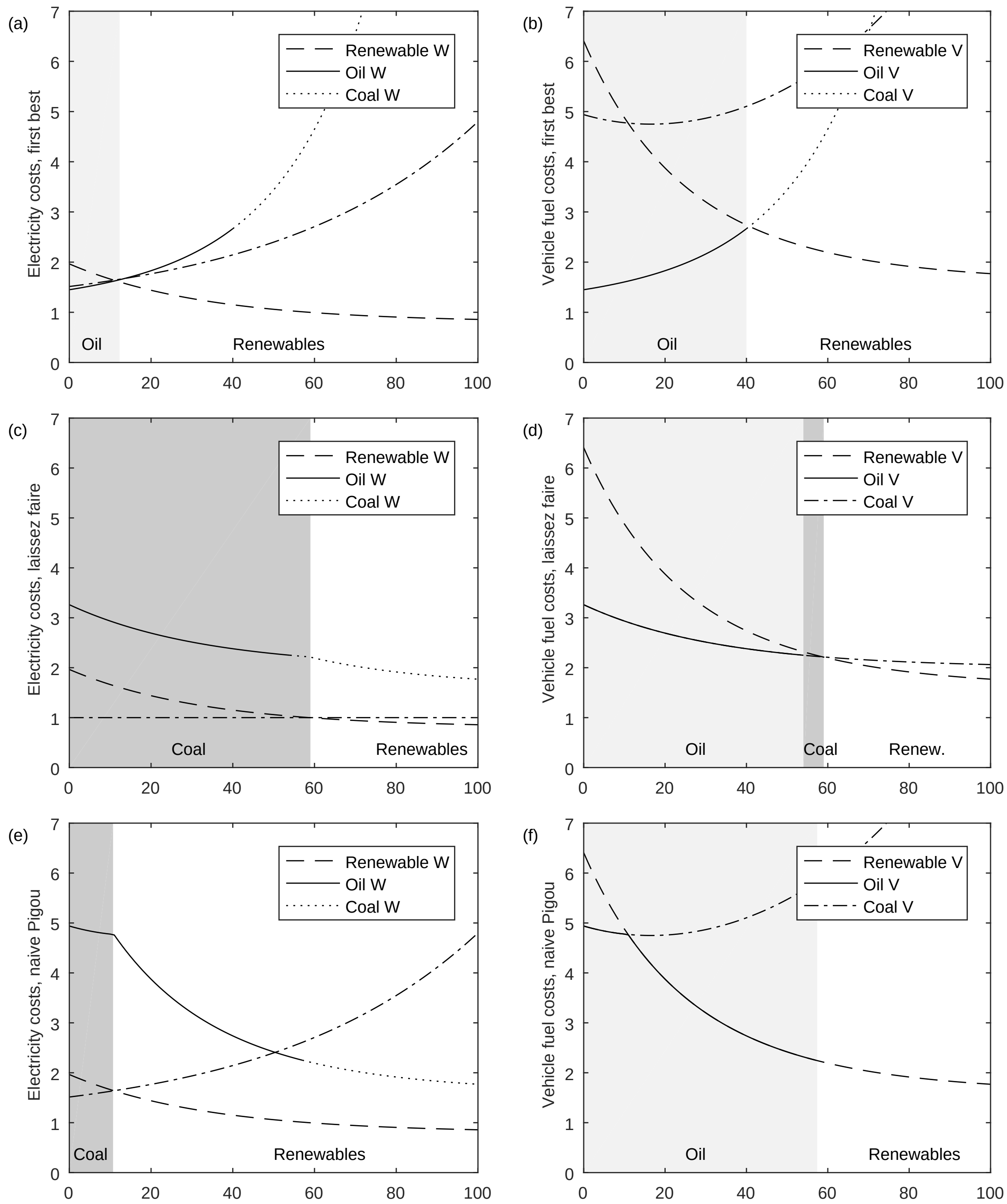
Elasticity of demand increases with price.



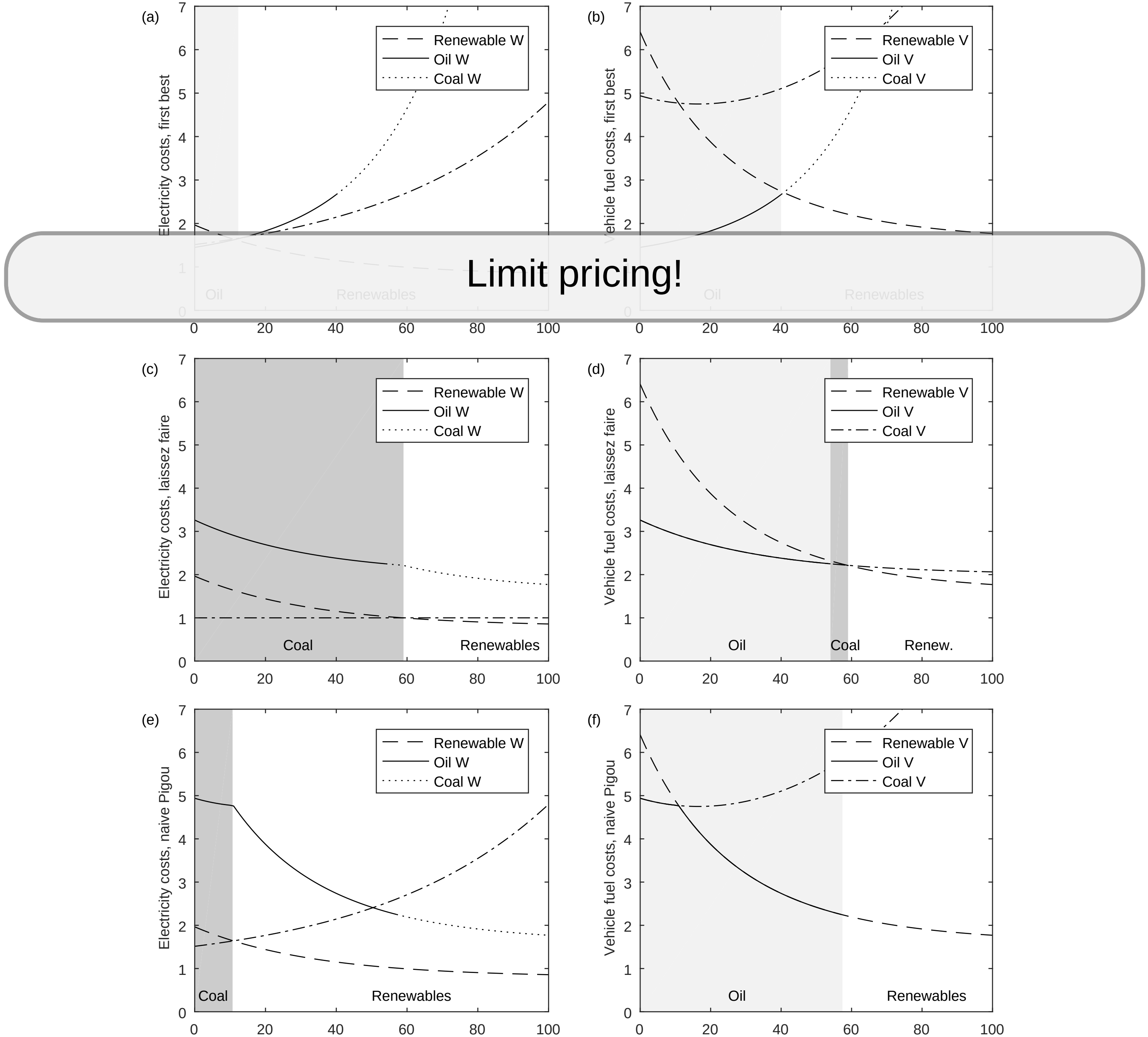
Numerical simulations



Costs of producing the intermediate goods: (a) private costs, electricity, (b) social costs, electricity, (c) private costs, vehicle fuel; and (d) social costs, vehicle fuel.



Input prices and input choices over time, in the two sectors and three scenarios.



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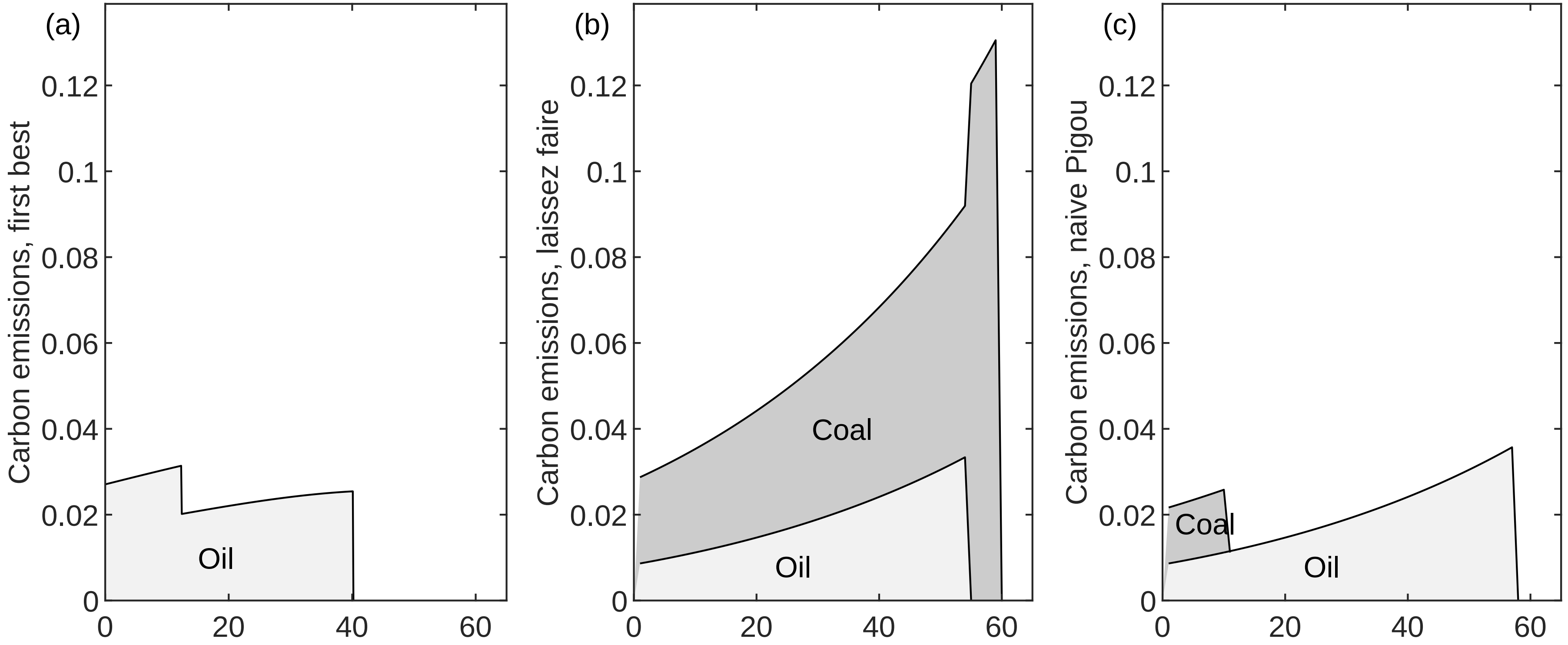
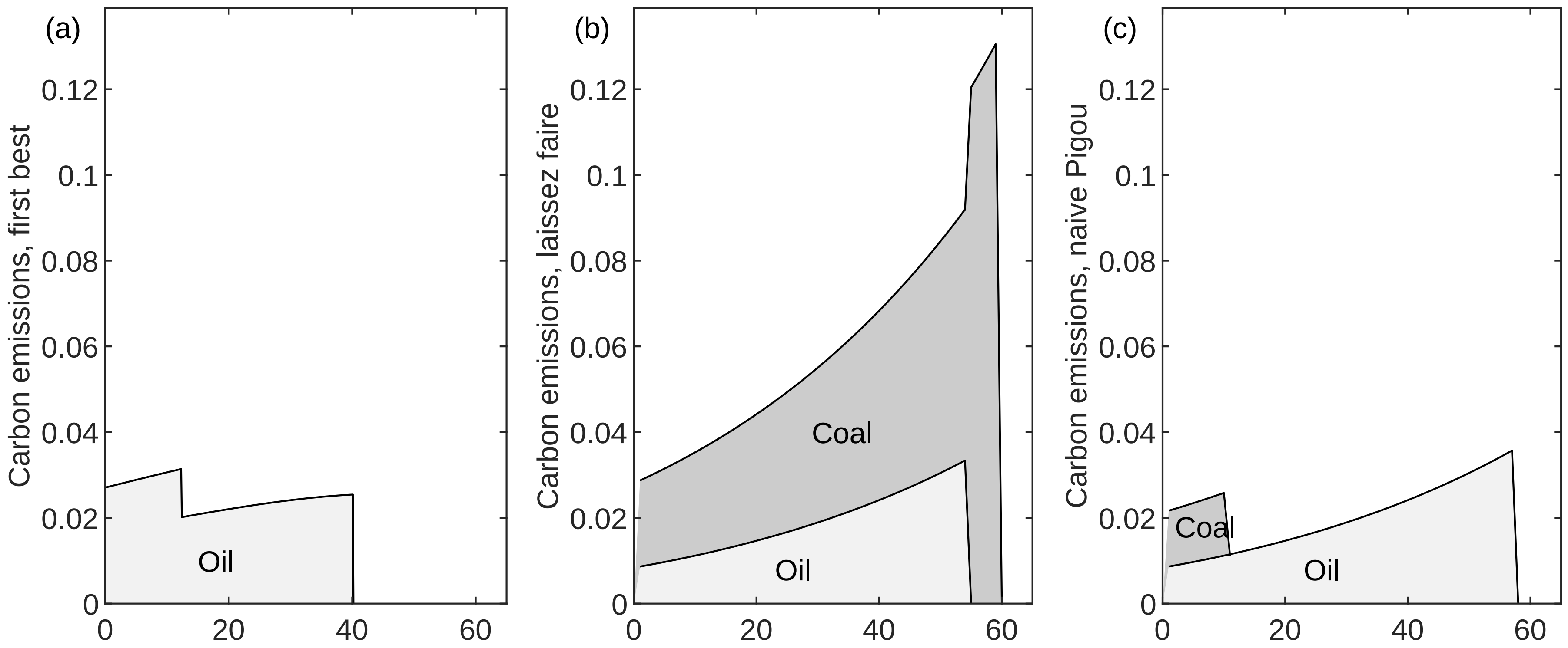


Carbon emissions from oil and coal over time, in the three scenarios.

First best:

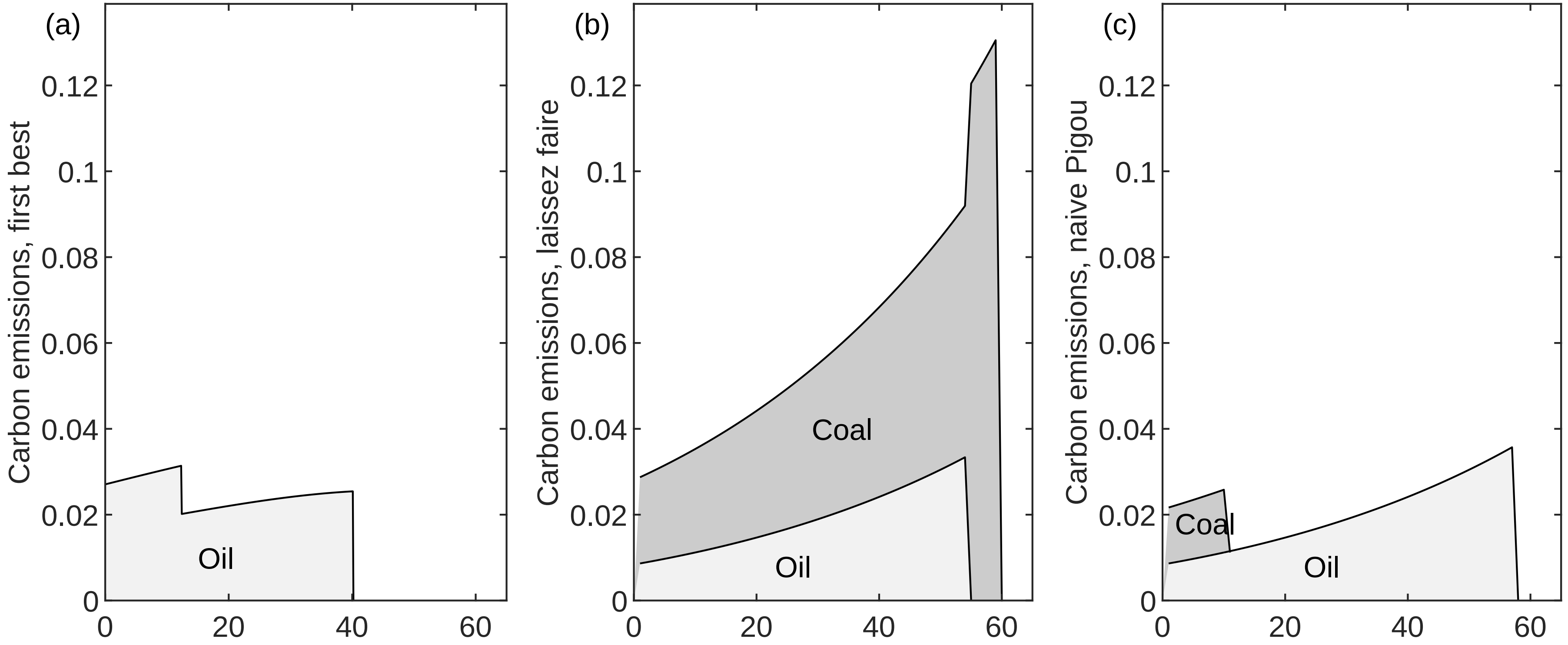
Oil/oil ... oil/renew ... renew/renew



Carbon emissions from oil and coal over time, in the three scenarios.

Laissez faire:

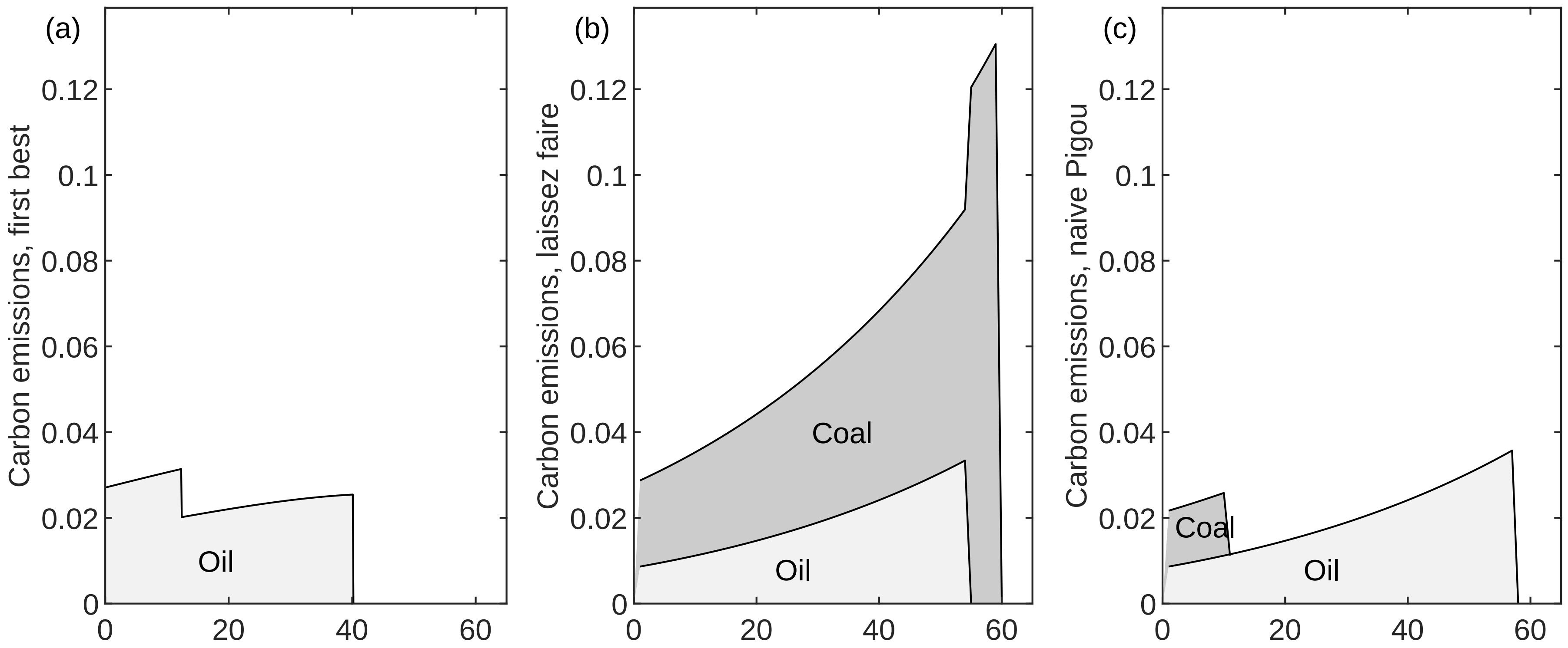
Oil (limit pricing)/coal ... coal/coal ... R/R.



Carbon emissions from oil and coal over time, in the three scenarios.

Pigou:

Oil (limit pricing)/coal ... oil/R ... R/R.



Carbon emissions from oil and coal over time, in the three scenarios.

Regulatory options

We now have all the ingredients we need to solve for the development of the economy, except the specification of the regulator's actions.
Three alternatives:

- Laissez-faire ($\tau = 0$);
- Naive Pigou ($\tau(t) = A_0 \psi e^{gt}$);
- First best.

First-best emissions regulation

First-best emissions regulation

Case 1, no exhaustion hence no scarcity rent.

First-best emissions regulation

Denote the time at which oil extraction stops as T^*. Uo to T^*,

$$\tau(t) = \frac{\epsilon - 1}{\epsilon}\psi e^{gt} - \frac{1}{\epsilon\phi_q}\left(u_q + \bar{p}_w^{-\delta/\epsilon}\bar{v}^{-1/\epsilon}\right). \tag{1}$$

After T^*, Pigou. Otherwise the monopolist will continue supplying oil at the limit price, excluding renewables and making a gradually dwindling surplus.

First-best emissions regulation

Recall that we denote the Pigovian tax $\tau^p(t)$. So $\tau^p(t) = \psi e^{gt}$, and

$$\frac{\tau^p(t) - \tau(t)}{\tau^p(t)} = \frac{1}{\epsilon} + \frac{1}{\epsilon\psi\phi_q}\left(u_q + \bar{p}_w^{-\delta/\epsilon}\bar{v}^{-1/\epsilon}\right)e^{-gt}. \quad (1)$$

So, by inspection, the first-best tax on oil is always less than the Pigovian tax, but as t increases from 0 to T^*, the percentage gap between the Pigovian tax and $\tau(t)$ decreases monotonically. However, note that the rate of increase of the tax (note, not the growth rate) $\dot{\tau} = [(\epsilon - 1)/\epsilon]g\psi e^{gt}$, which is less than the rate of increase of the Pigovian tax, $\dot{\tau}^p = g\psi e^{gt}$.

First-best emissions regulation

Case 2, exhaustion.

First-best emissions regulation

We choose the tax path which leads to zero scarcity rent, implying that the tax per unit of oil payable by the oil producer at the time of exhaustion is equal to the current value of the planner's scarcity rent at that time, $\phi_q \tau(T) = \mu^* e^{rT}$.

Then

$$\tau(t) = \frac{\mu^* e^{rT}}{\phi_q} - \frac{\epsilon - 1}{\epsilon}\psi(e^{gT} - e^{gt}).$$

Note that the rate of increase of this tax is, as above, $[(\epsilon - 1)/\epsilon]g\psi e^{gt}$, which is (again) less than the rate of increase of the Pigovian tax.

Opposite conclusion compared to 'green paradox' models in which a steeply increasing carbon tax increases emissions compared to laissez faire.

Conclusions

An oil monopoly may increase total carbon emissions under naive (Pigovian) regulation by encouraging the use of coal which would (in first best) remain in the ground.

In our very simple set-up with a single economy and a focus on the optimal allocation of productive resources (and no attention paid to the distribution of income), the policy implication is that if a Pigovian tax is applied, there should also be a subsidy to oil consumption, which gradually declines over time as the market power of the oil monopolist weakens.

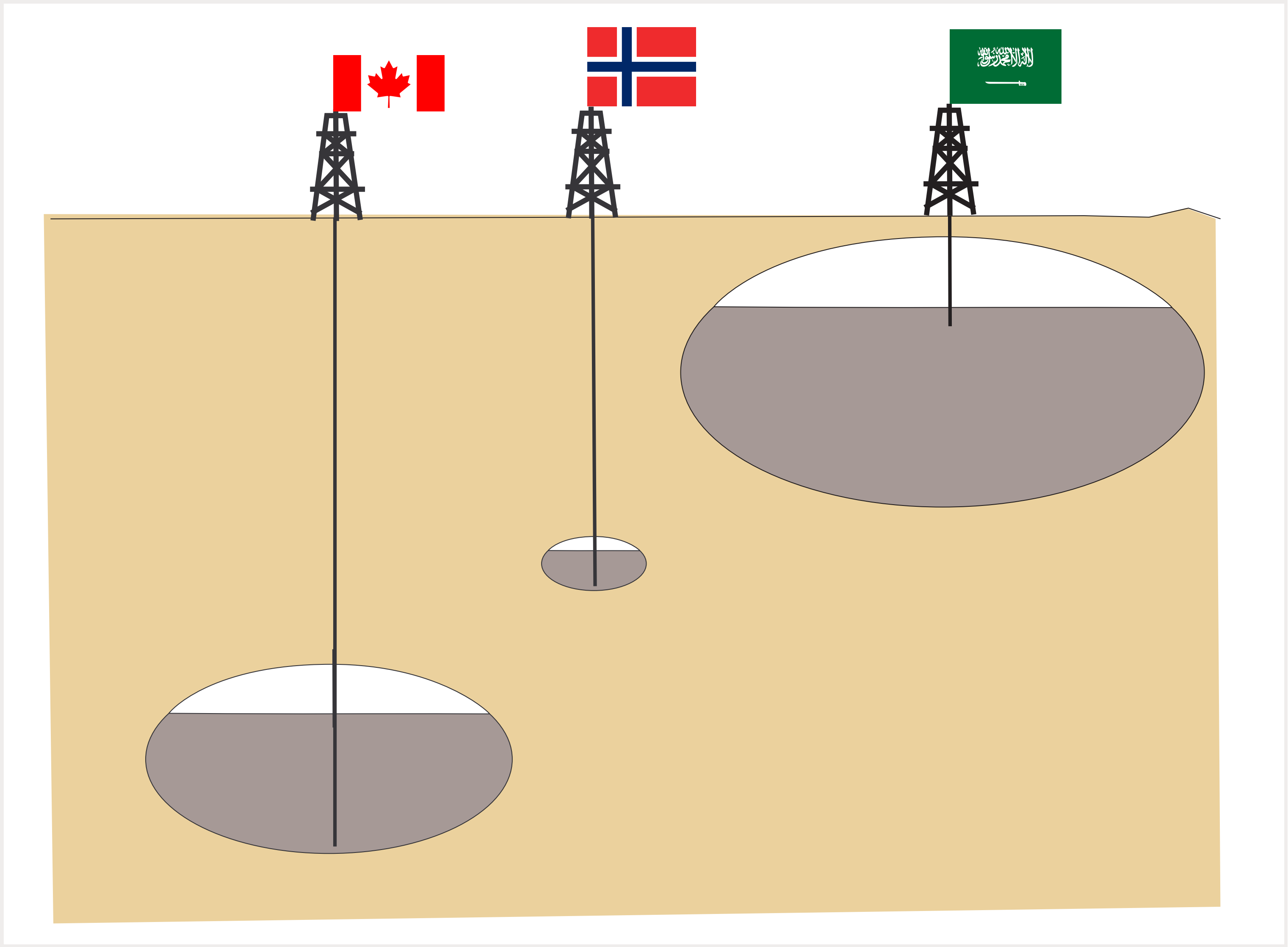
In a more realistic setting with multiple countries and distributional concerns, subsidizing oil consumption is unlikely to be an acceptable (or optimal) policy option.

Under these circumstances the simplest strategy might be to simply ban the use of coal, or (in a multicountry setting) buy foreign coal deposits (cf. Harstad 2012 and others).

The benchmark model is very highly stylized, and a key drawback is that we assume a single homogeneous oil stock, and an oil monopolist.

Next paper: model an oil cartel with a large homogeneous stock, and a series of competitors with smaller stocks which were also more expensive to extract: oligopoly in the oil market, or (to quote Loury, 1986), oiligopoly.

As here, market power applied by the cartel leads to extraction from more expensive sources (even under naive Pigou), stocks that would be left in ground in first best.

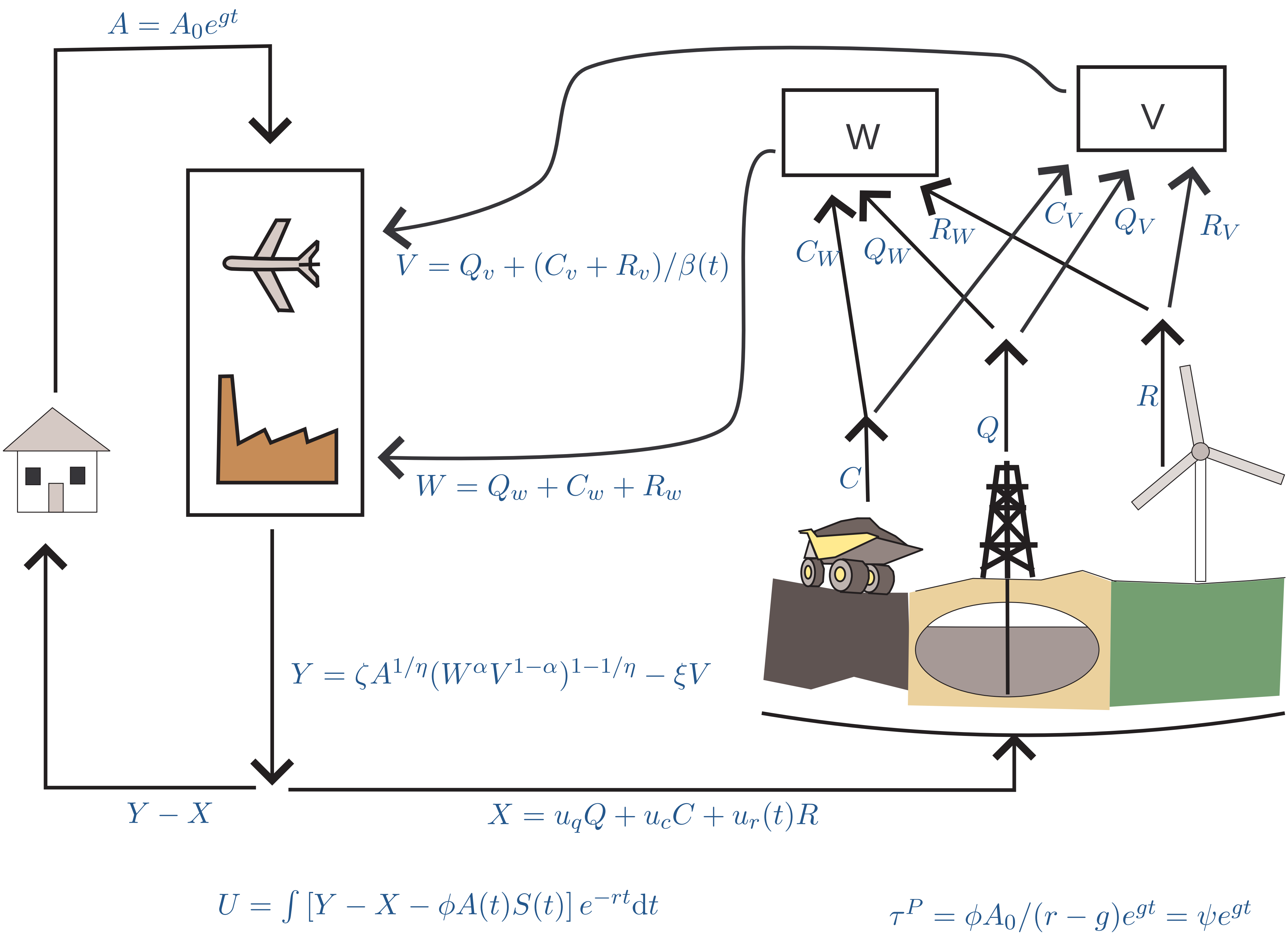


Oil price 50 USD/barrel. Extraction costs 49 USD/barrel. Low extraction rate = price taker?

Appendices

Solving for demand and supply

Energy demand



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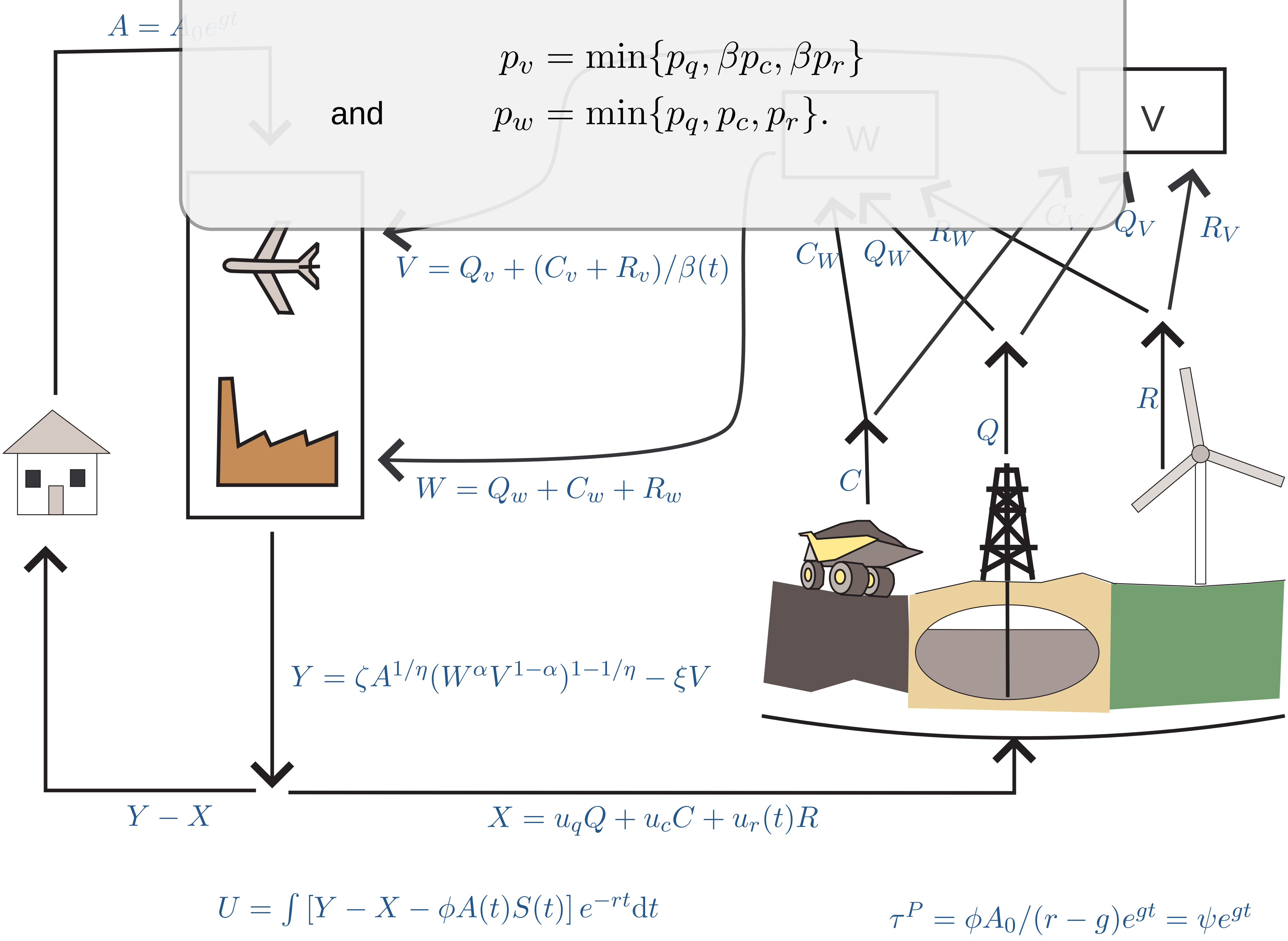
$$p_v = \min\{p_q, \beta p_c, \beta p_r\}$$

and $$p_w = \min\{p_q, p_c, p_r\}.$$



$$p_v = \min\{p_q, \beta p_c, \beta p_r\}$$

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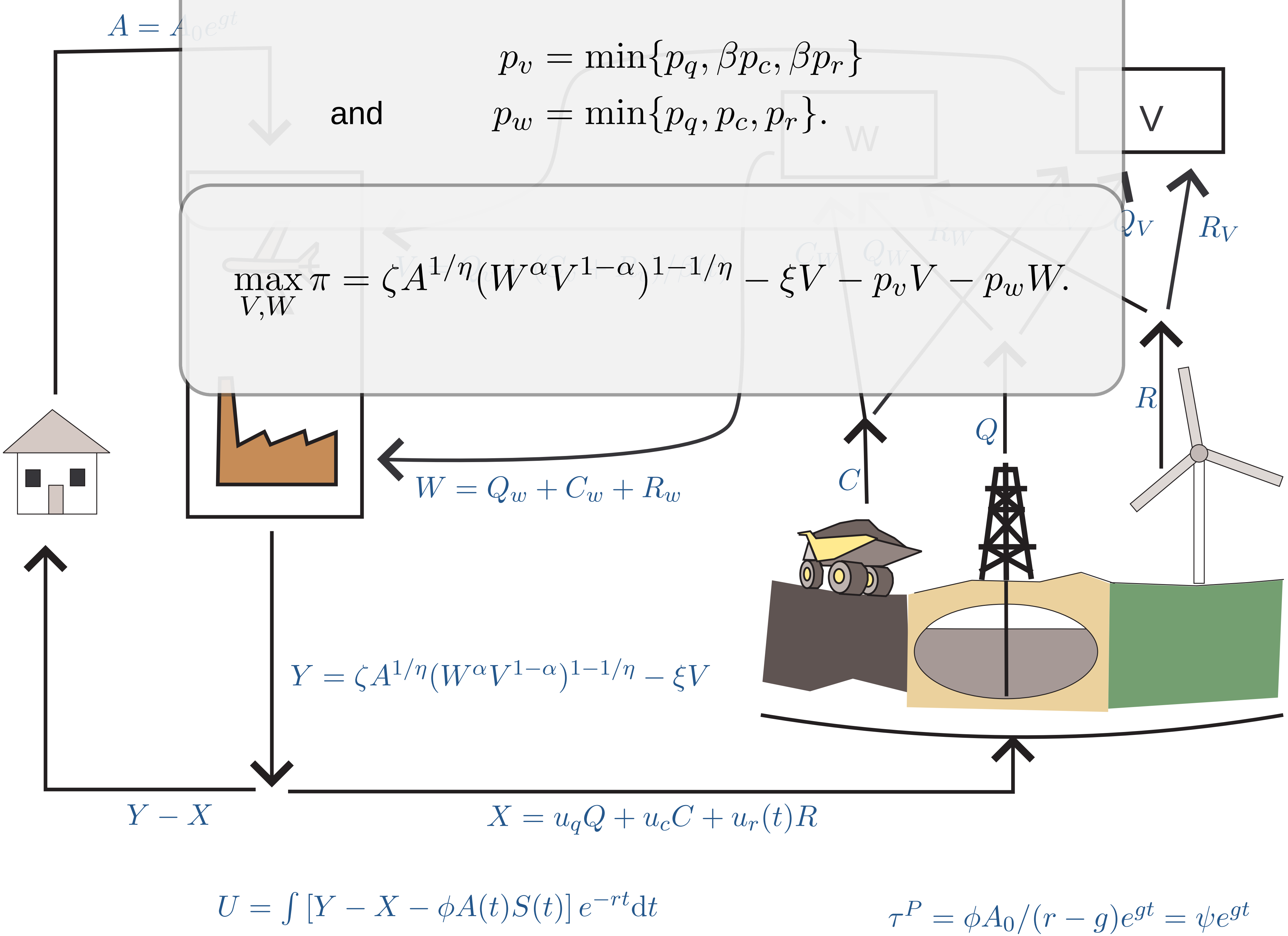
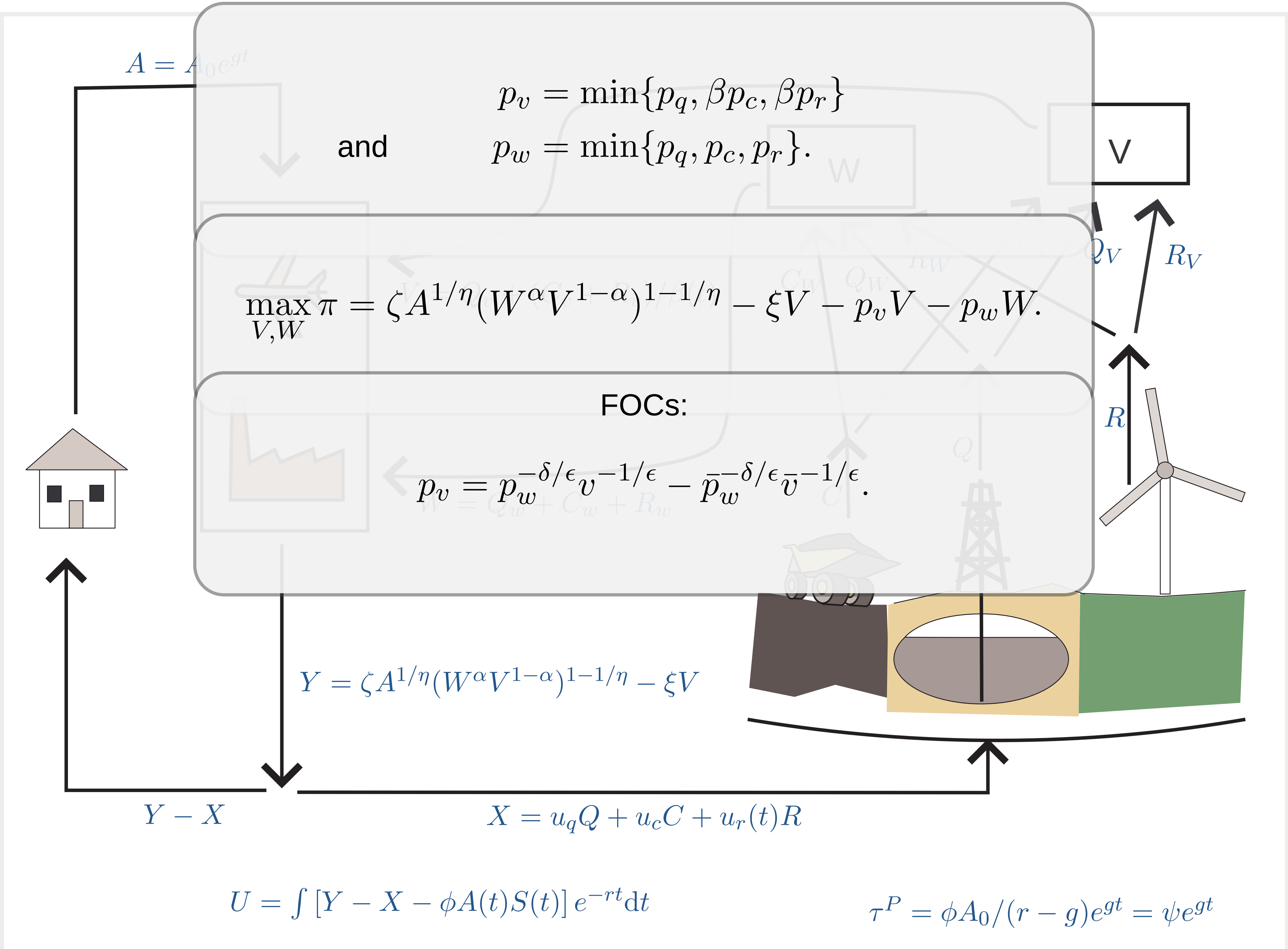
$$\max_{V,W} \pi = \zeta A^{1/\eta}(W^\alpha V^{1-\alpha})^{1-1/\eta} - \xi V - p_v V - p_w W.$$





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FOCs:
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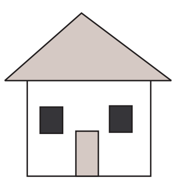
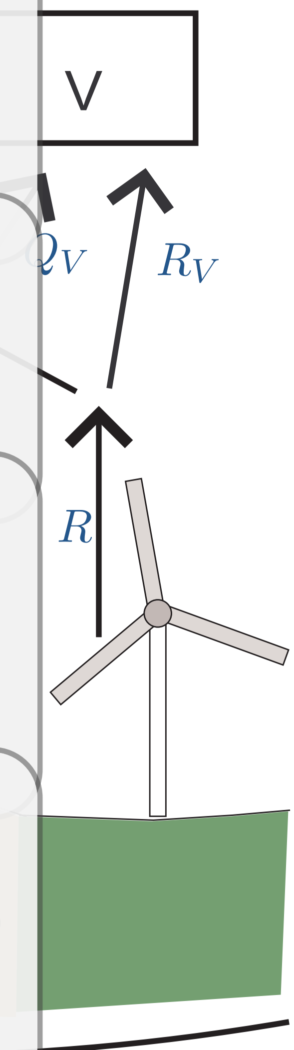
Definitions:

$$\zeta = (1 + \epsilon/\delta)[\delta/(\epsilon - 1)]^{\epsilon/(\epsilon+\delta)} \quad \text{and} \quad \xi = \bar{p}_w^{-\delta/\epsilon} \bar{v}^{-1/\epsilon}.$$

$$v = V/A.$$

And $\bar{v}$ is vehicle energy demanded when the price of electricity is $\bar{p}_w$ and the price of vehicle fuel is zero.





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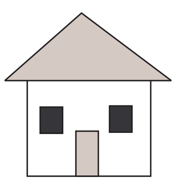
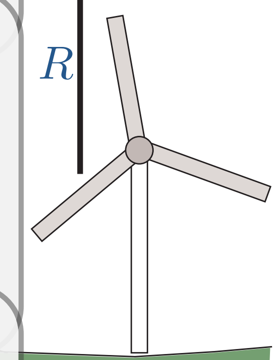
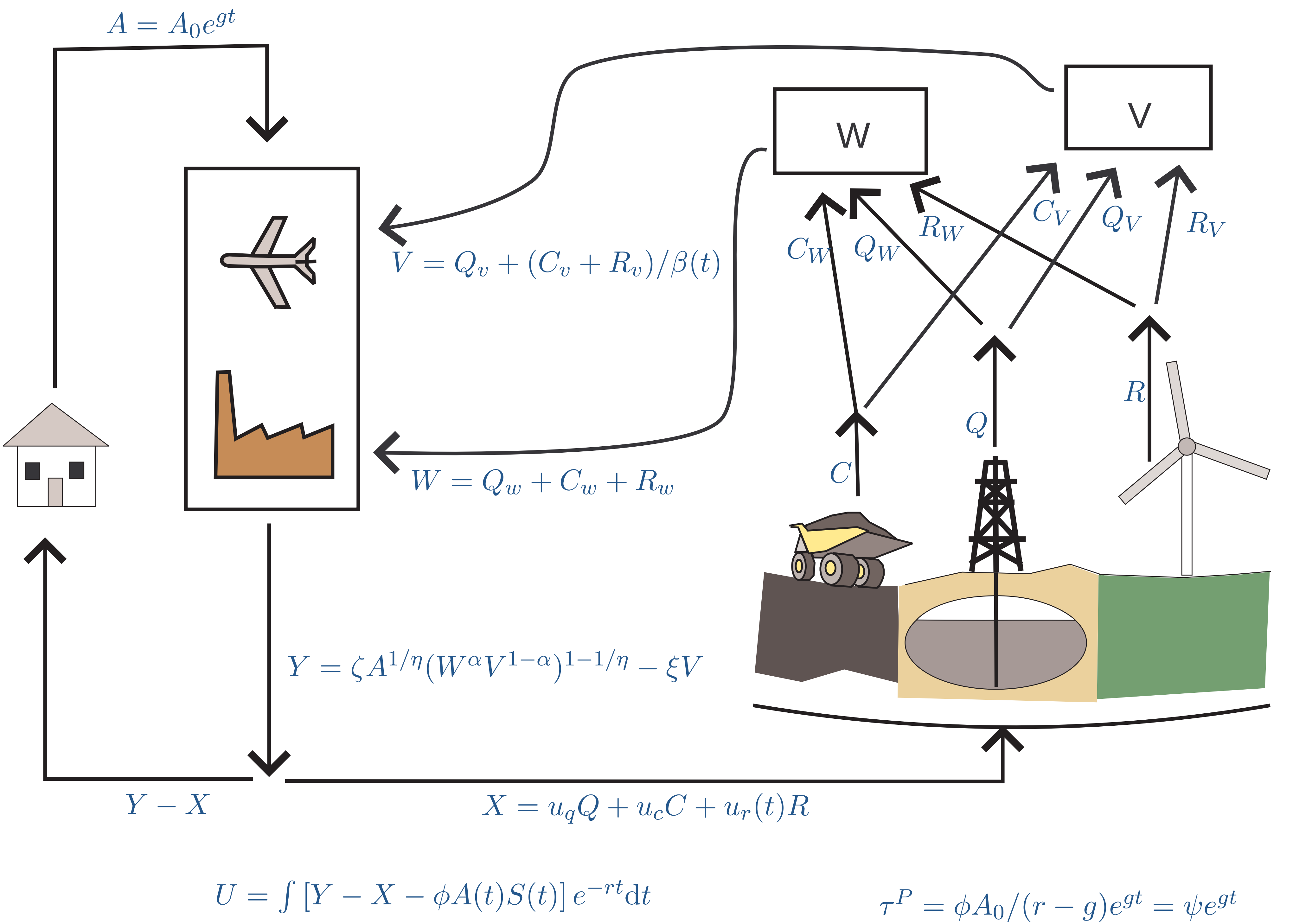
As price increases, elasticity of demand increases towards a limit of ϵ.





First-best supply



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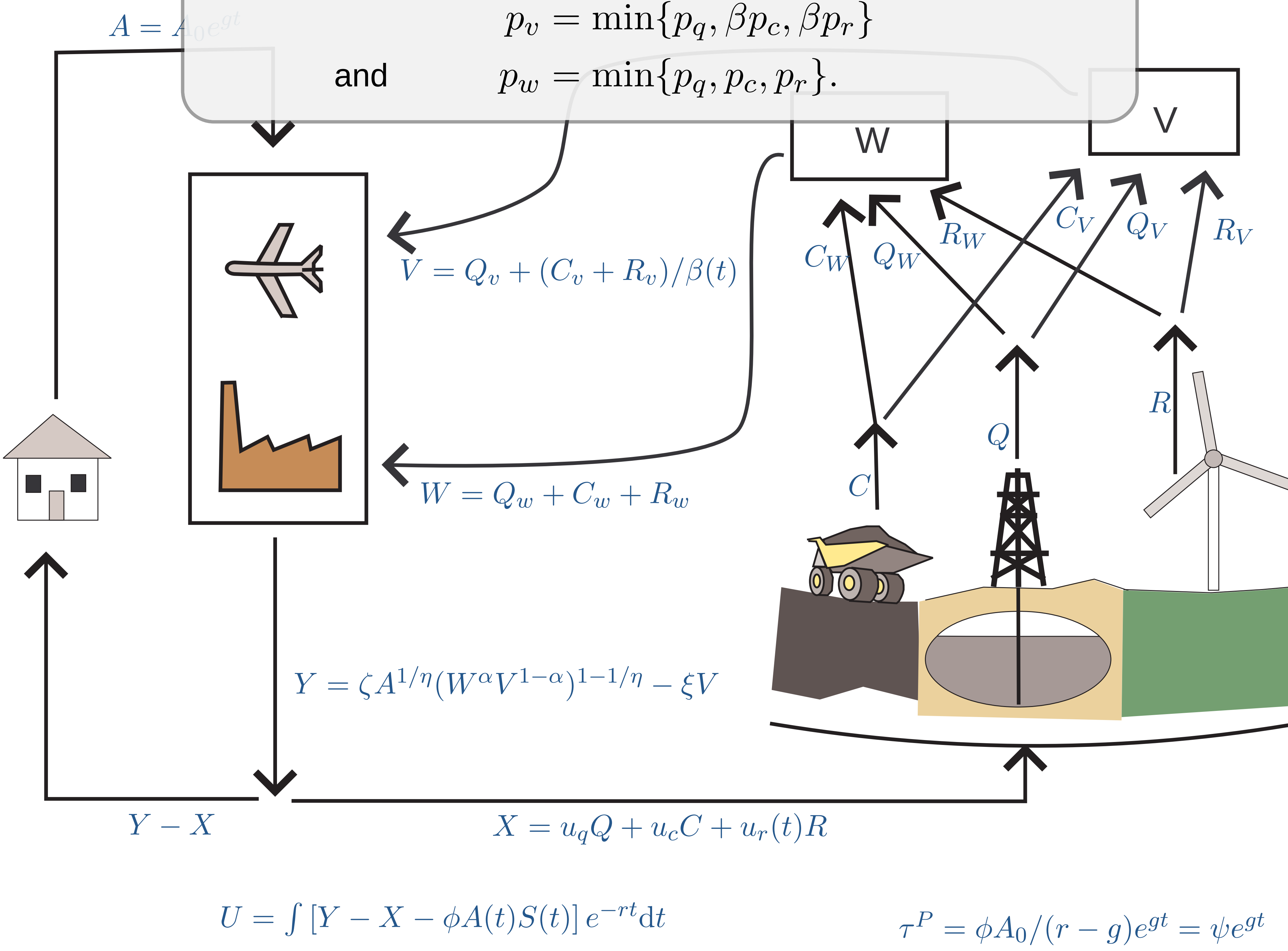

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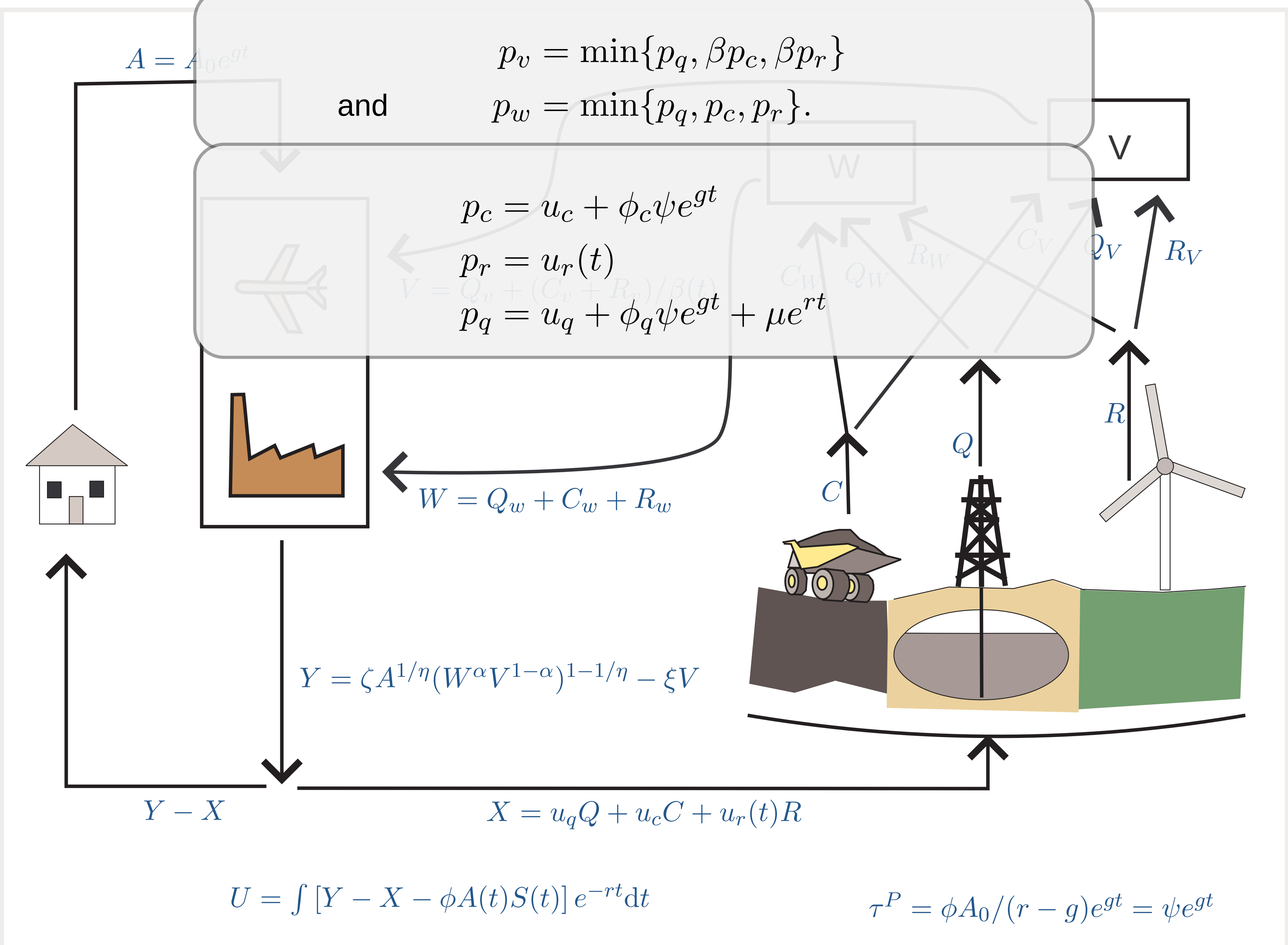
$$p_c = u_c + \phi_c \psi e^{gt}$$

$$p_r = u_r(t)$$

$$p_q = u_q + \phi_q \psi e^{gt} + \mu e^{rt}$$



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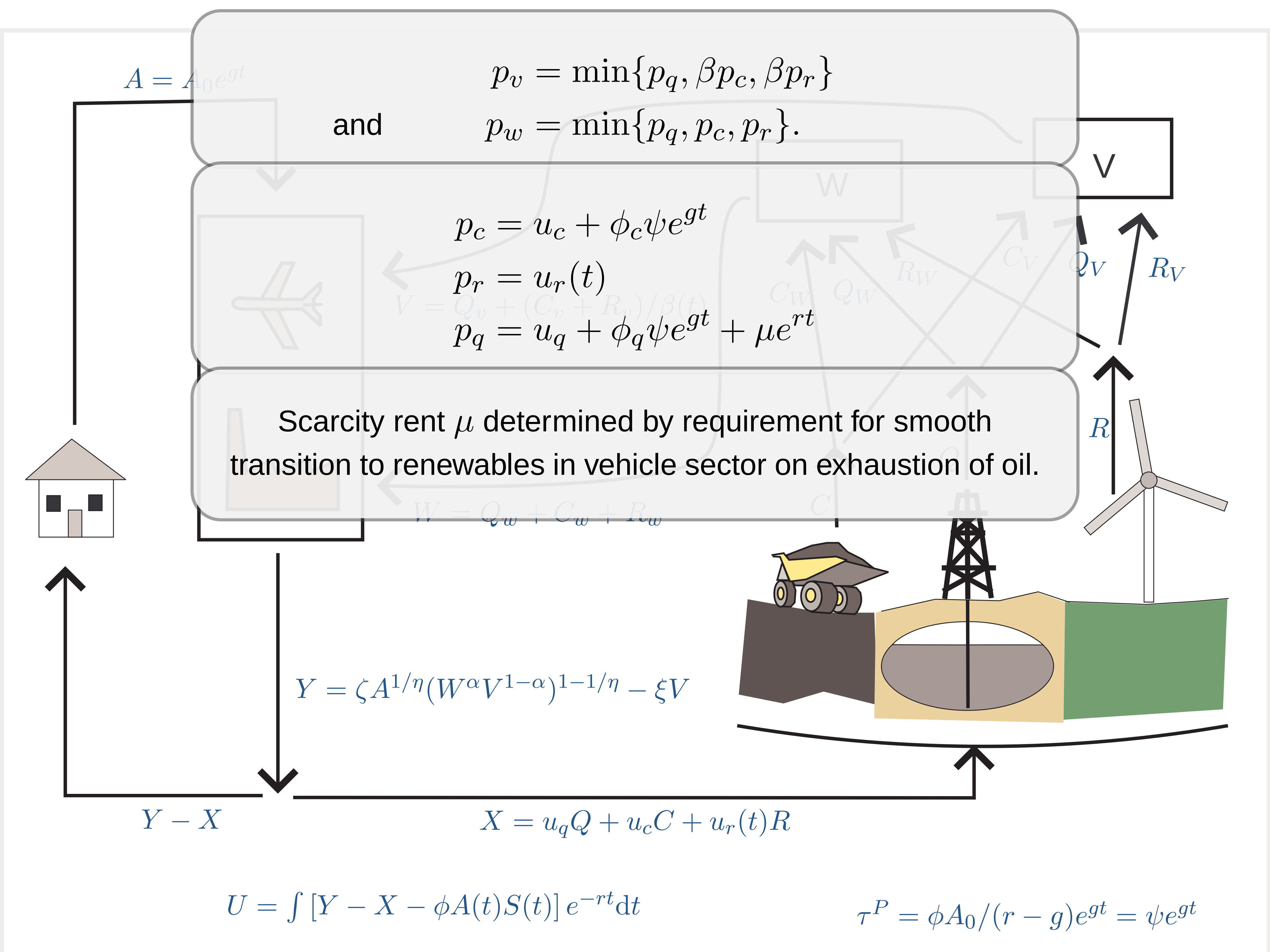
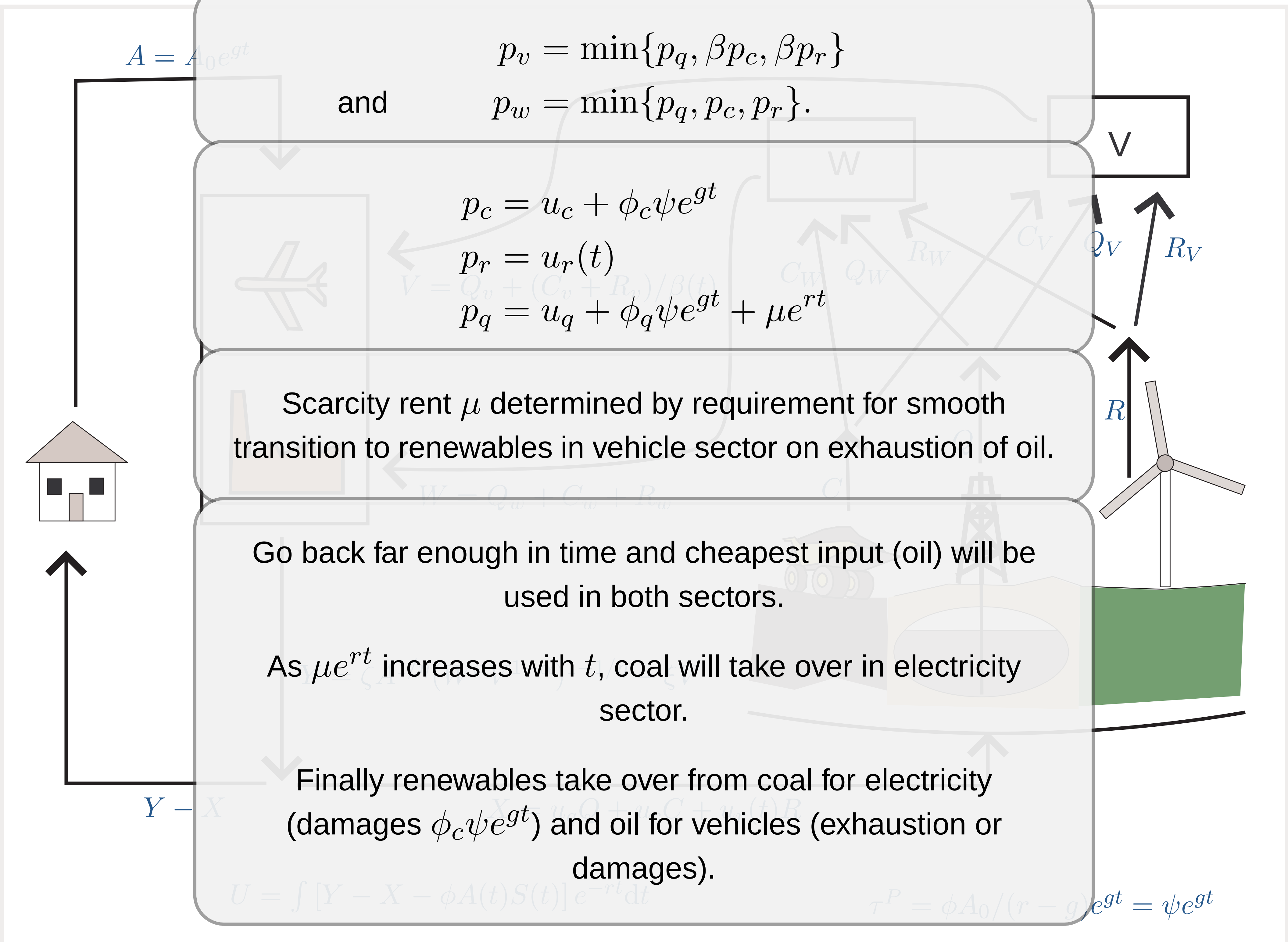
$$p_c = u_c + \phi_c \psi e^{gt}$$

$$p_r = u_r(t)$$

$$p_q = u_q + \phi_q \psi e^{gt} + \mu e^{rt}$$

Scarcity rent μ determined by requirement for smooth transition to renewables in vehicle sector on exhaustion of oil.





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and $$p_w = \min\{p_q, p_c, p_r\}.$$

$$p_c = u_c + \phi_c \psi e^{gt}$$
$$p_r = u_r(t)$$
$$p_q = u_q + \phi_q \psi e^{gt} + \mu e^{rt}$$

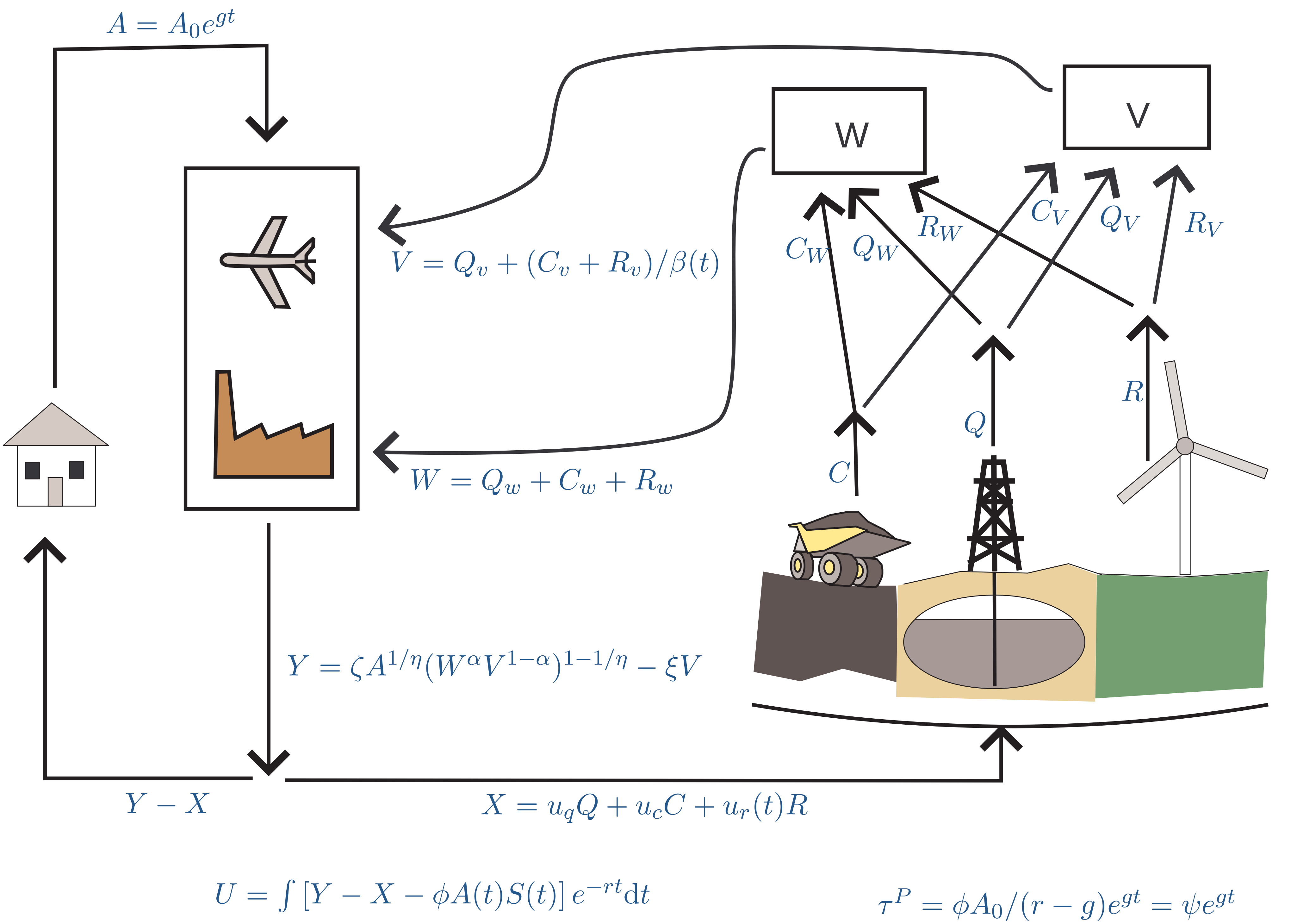
Scarcity rent μ determined by requirement for smooth transition to renewables in vehicle sector on exhaustion of oil.

Go back far enough in time and cheapest input (oil) will be used in both sectors.

As μe^{rt} increases with t, coal will take over in electricity sector.

Finally renewables take over from coal for electricity (damages $\phi_c \psi e^{gt}$) and oil for vehicles (exhaustion or damages).

Monopolistic oil supply, no exhaustion



$A = A_0 e^{gt}$
W
V
C_W
Q_W
R_W
C_V
Q_V
R_V
$V = Q_v + (C_v + R_v)/\beta(t)$
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Q
C
$Y = \zeta A^{1/\eta}(W^{\alpha}V^{1-\alpha})^{1-1/\eta} - \xi V$
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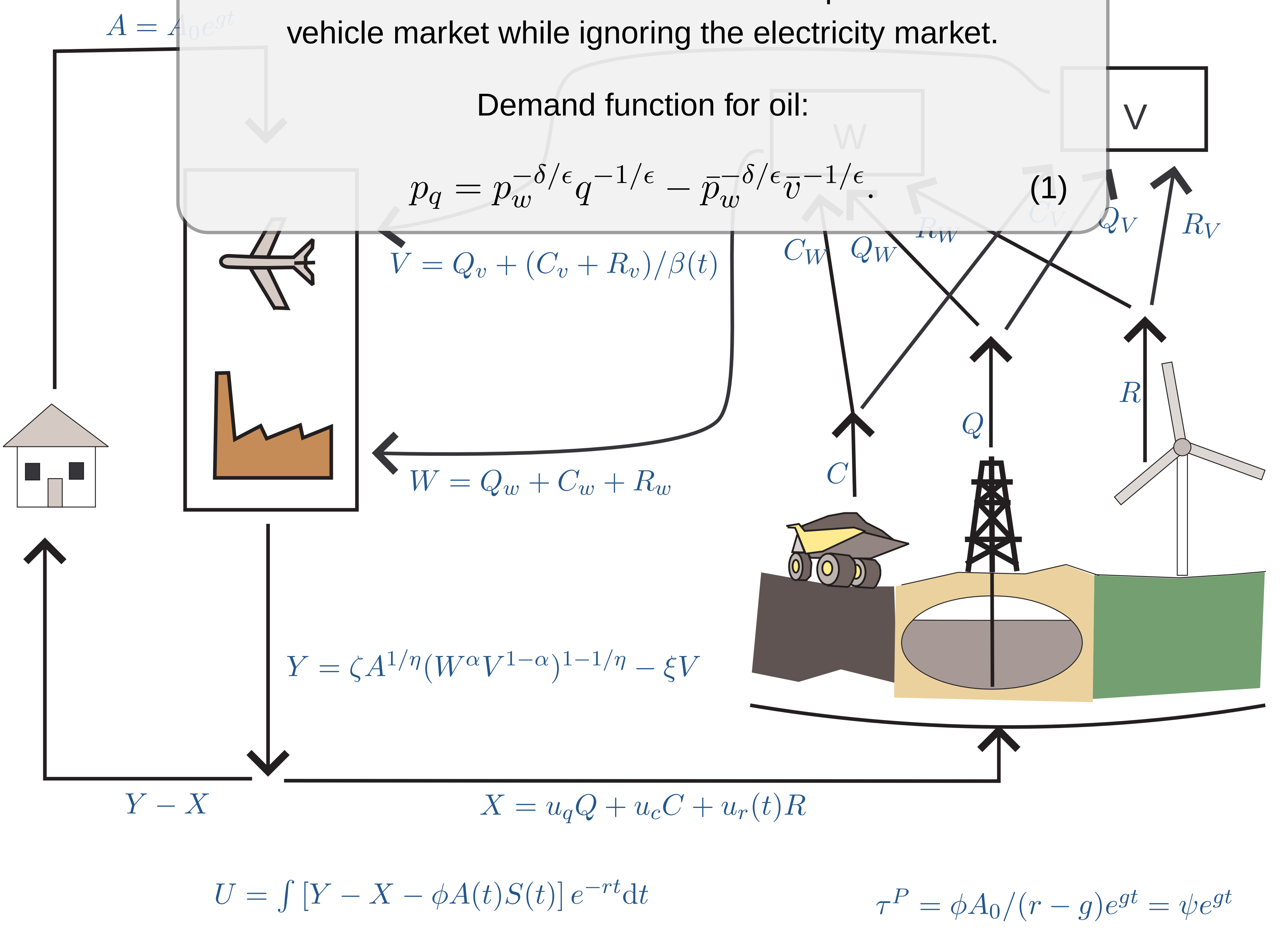
$X = u_q Q + u_c C + u_r(t) R$
$U = \int [Y - X - \phi A(t) S(t)]\, e^{-rt} \mathrm{d}t$
$\tau^P = \phi A_0/(r-g) e^{gt} = \psi e^{gt}$

We focus on the case in which the oil monopolist corners the vehicle market while ignoring the electricity market.

Demand function for oil:

$$p_q = p_w^{-\delta/\epsilon} q^{-1/\epsilon} - \bar{p}_w^{-\delta/\epsilon} \bar{v}^{-1/\epsilon}. \quad (1)$$



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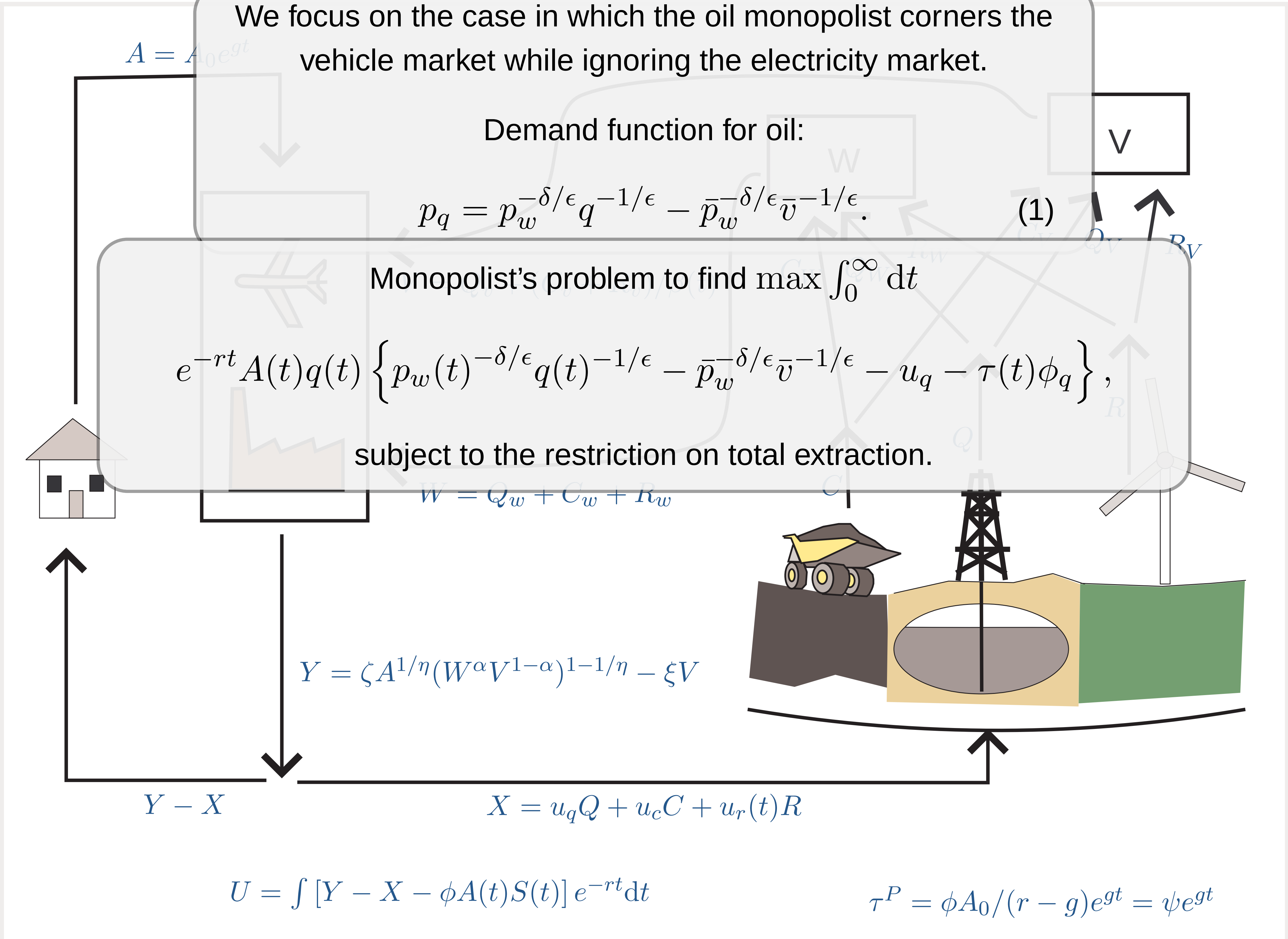
Monopolist's problem to find $\max \int_0^\infty \mathrm{d}t$

$$e^{-rt} A(t) q(t) \left\{ p_w(t)^{-\delta/\epsilon} q(t)^{-1/\epsilon} - \bar{p}_w^{-\delta/\epsilon} \bar{v}^{-1/\epsilon} - u_q - \tau(t)\phi_q \right\},$$

subject to the restriction on total extraction.



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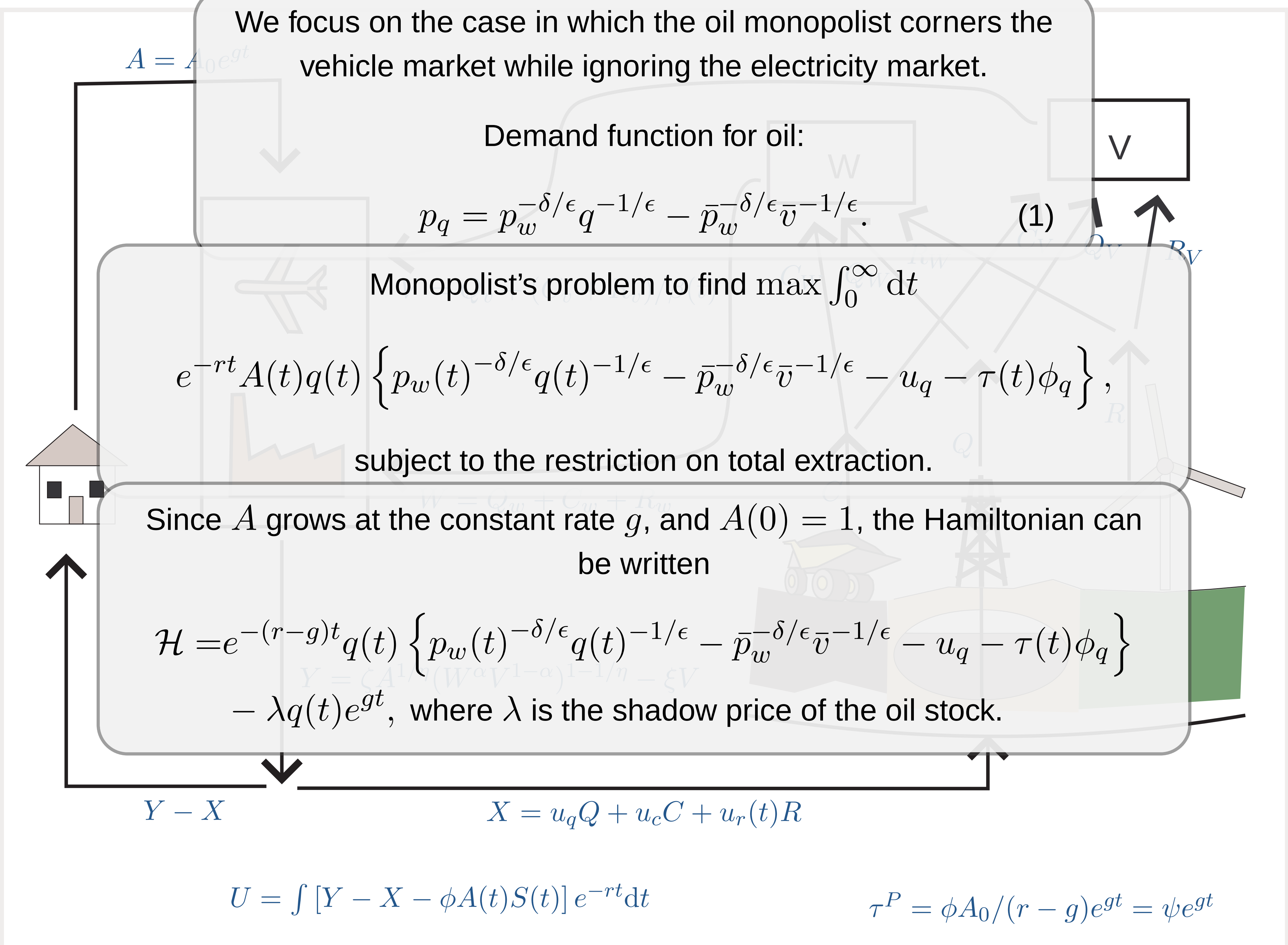
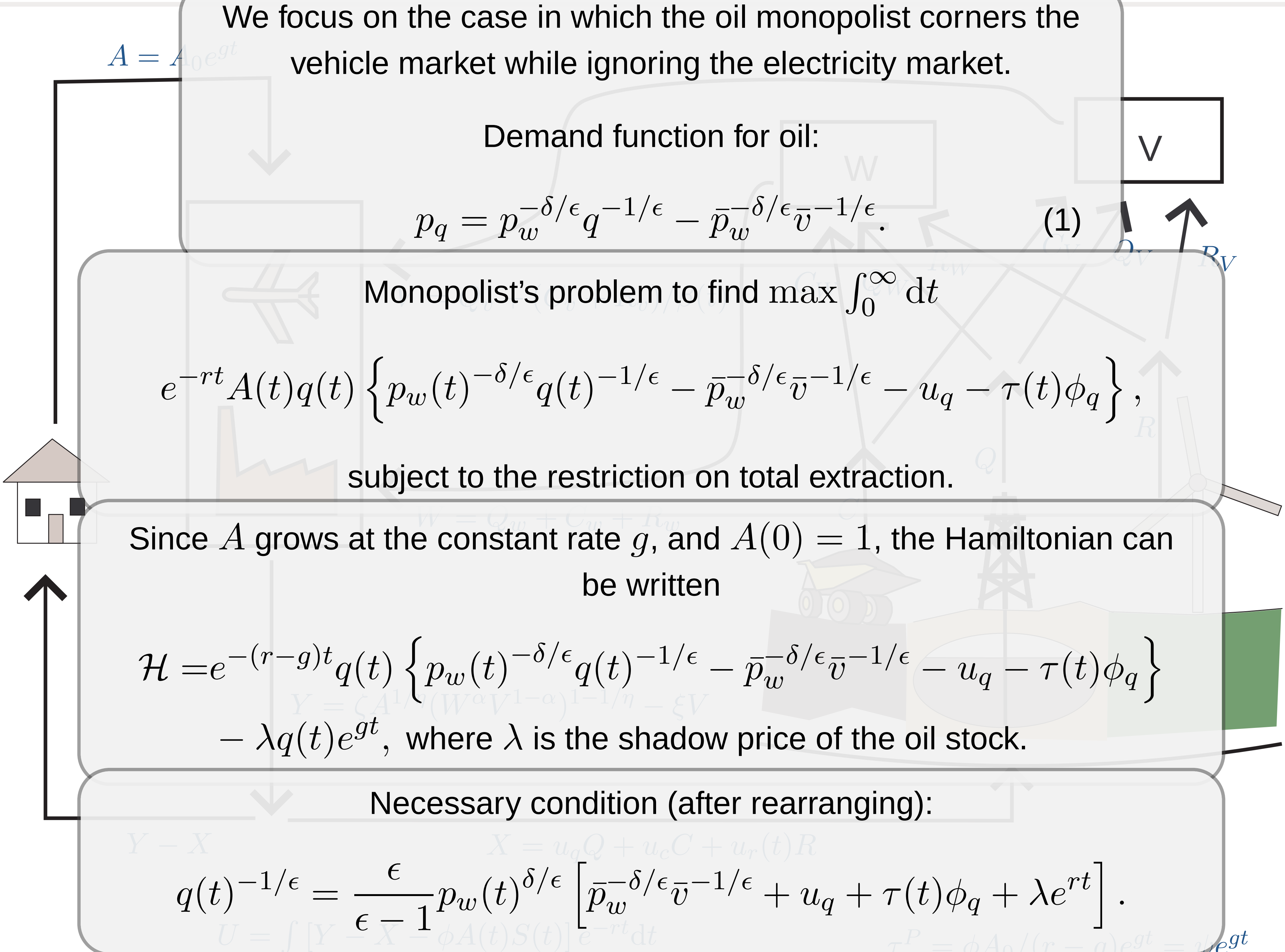
subject to the restriction on total extraction.

Since A grows at the constant rate g, and $A(0) = 1$, the Hamiltonian can be written

$$\mathcal{H} = e^{-(r-g)t} q(t) \left\{ p_w(t)^{-\delta/\epsilon} q(t)^{-1/\epsilon} - \bar{p}_w^{-\delta/\epsilon} \bar{v}^{-1/\epsilon} - u_q - \tau(t)\phi_q \right\}$$

$- \lambda q(t) e^{gt}$, where λ is the shadow price of the oil stock.





We focus on the case in which the oil monopolist corners the vehicle market while ignoring the electricity market.

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Monopolist's problem to find $\max \int_0^\infty \mathrm{d}t$

$$e^{-rt} A(t) q(t) \left\{ p_w(t)^{-\delta/\epsilon} q(t)^{-1/\epsilon} - \bar{p}_w^{-\delta/\epsilon} \bar{v}^{-1/\epsilon} - u_q - \tau(t)\phi_q \right\},$$

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Necessary condition (after rearranging):

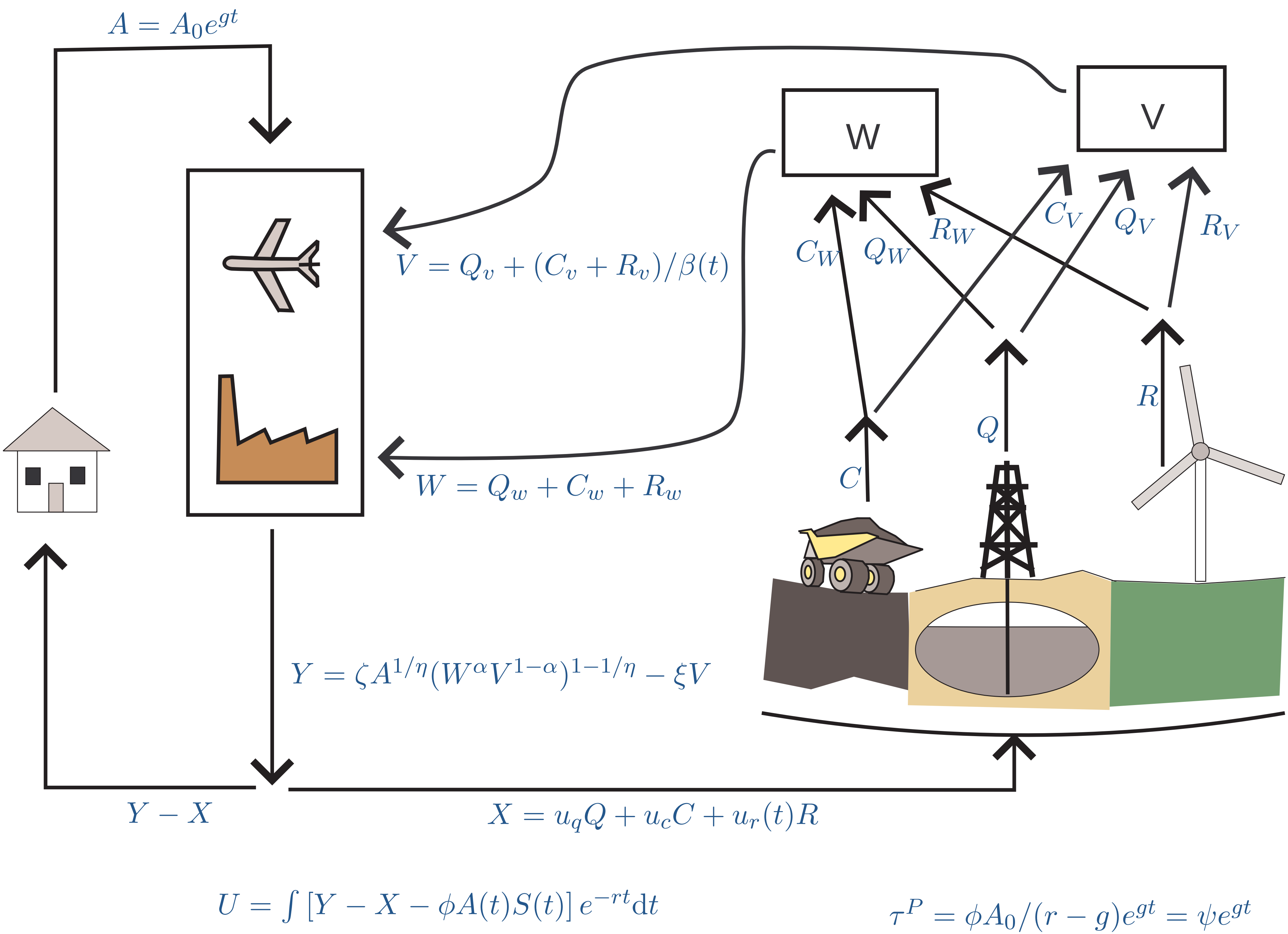
$$q(t)^{-1/\epsilon} = \frac{\epsilon}{\epsilon - 1} p_w(t)^{\delta/\epsilon} \left[\bar{p}_w^{-\delta/\epsilon} \bar{v}^{-1/\epsilon} + u_q + \tau(t)\phi_q + \lambda e^{rt} \right].$$

In the simplest case oil is never exhausted, $\lambda = 0$, and we can substitute our result into the inverse demand function to yield an equation for the price path as a function of the emissions tax path, assuming an internal solution.

However, we must also account for the possibility of limit pricing; the oil price in the transport sector cannot be higher than the prices at which coal or renewables would be chosen instead. Therefore we have

$$p_q(t) = \min \Big\{ \beta(t)(u_c + \phi_c \tau(t)), \\ \beta(t) u_r(t), \\ \frac{1}{\epsilon - 1} \bar{p}_w^{-\delta/\epsilon} \bar{v}^{-1/\epsilon} + \frac{\epsilon}{\epsilon - 1}(u_q + \phi_q \tau(t)) \Big\}.$$

Monopolistic oil supply, exhaustion



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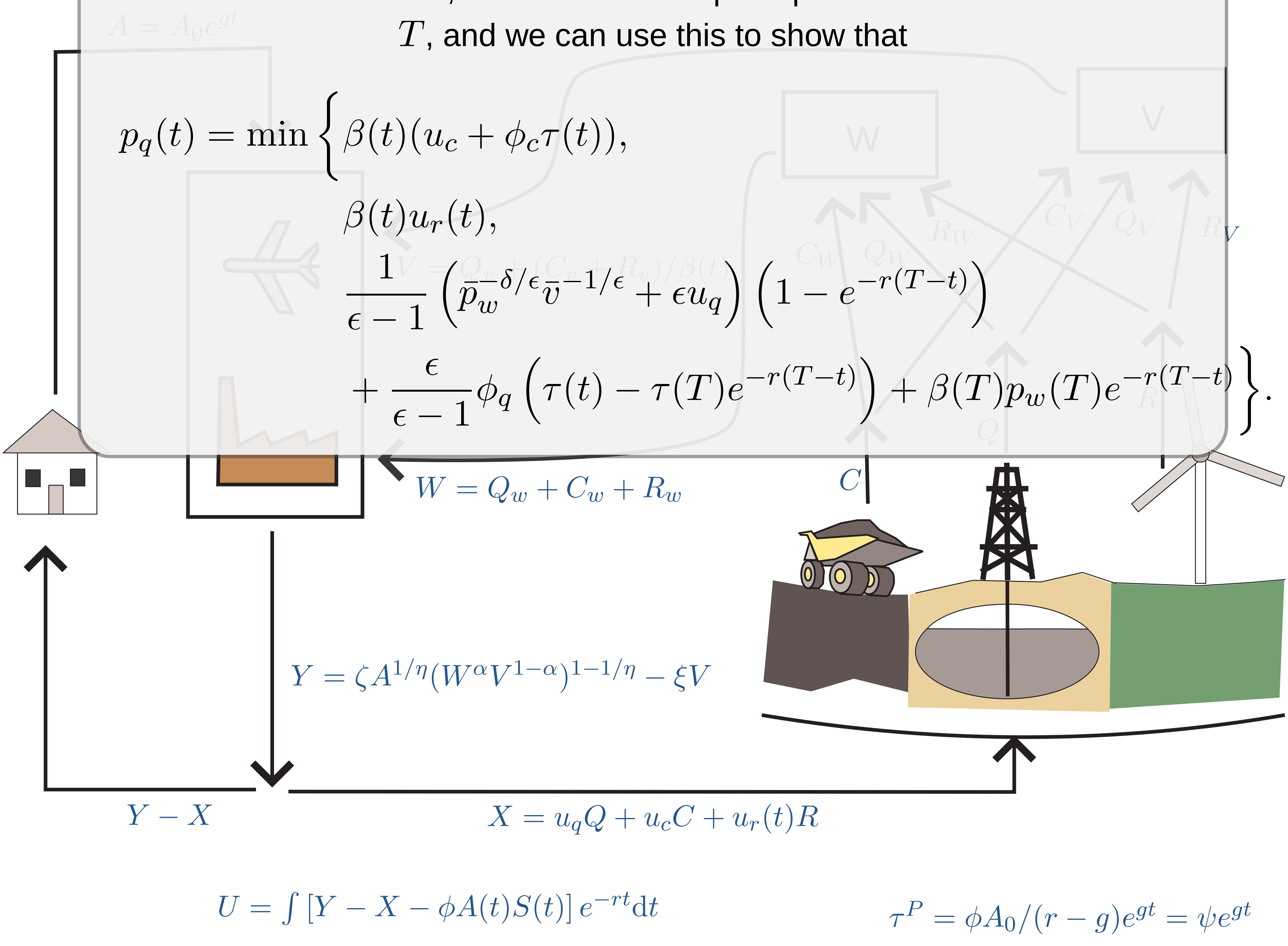
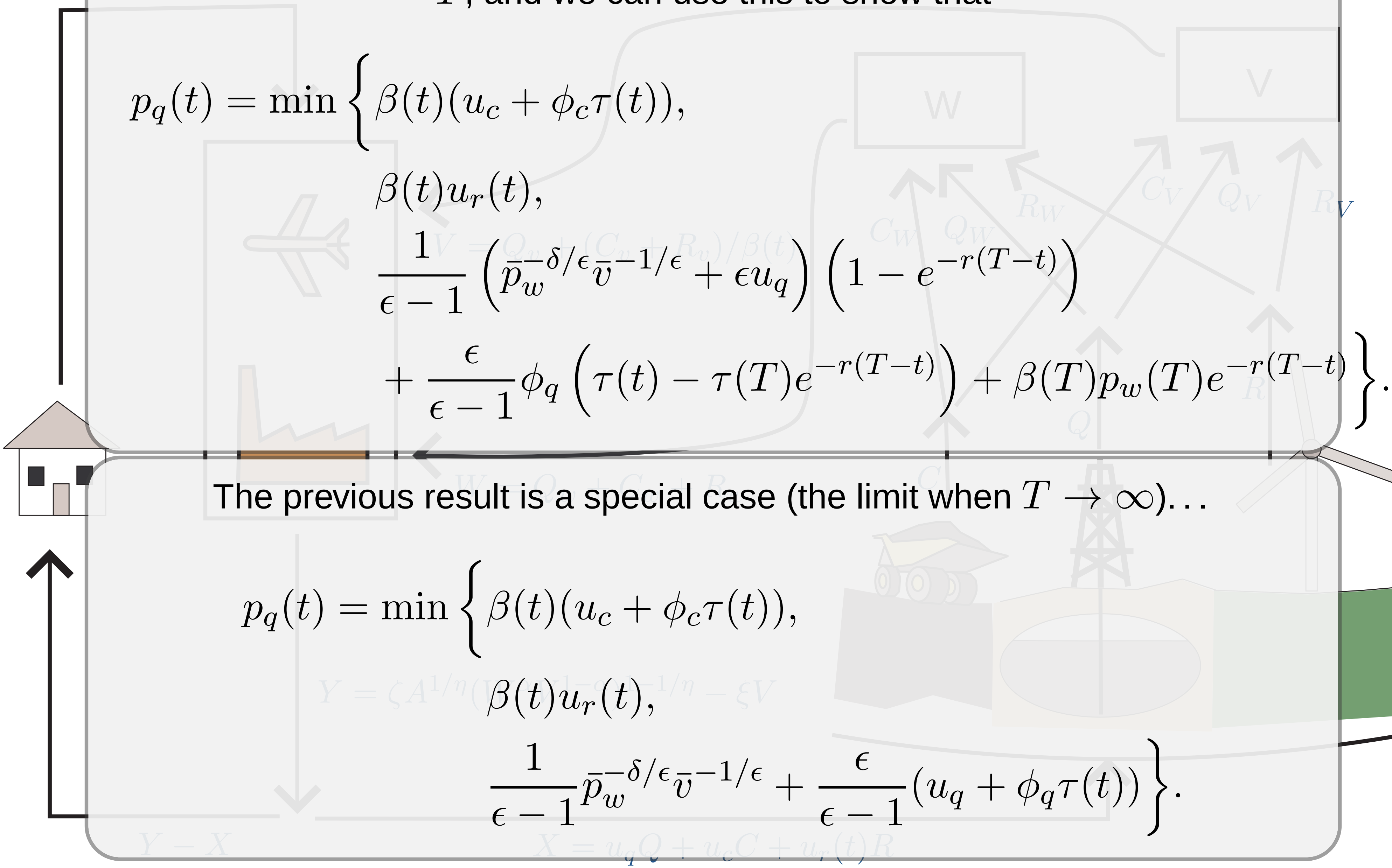
$U = \int [Y - X - \phi A(t) S(t)]\, e^{-rt} \mathrm{d}t$
$\tau^P = \phi A_0/(r-g) e^{gt} = \psi e^{gt}$

Given exhaustion at T, we know that the price path must be continuous at T, and we can use this to show that

$$p_q(t) = \min\Big\{\beta(t)(u_c + \phi_c\tau(t)),\ \beta(t)u_r(t),\ \frac{1}{\epsilon-1}\left(\bar{p}_w^{-\delta/\epsilon}\bar{v}^{-1/\epsilon} + \epsilon u_q\right)\left(1 - e^{-r(T-t)}\right) + \frac{\epsilon}{\epsilon-1}\phi_q\left(\tau(t) - \tau(T)e^{-r(T-t)}\right) + \beta(T)p_w(T)e^{-r(T-t)}\Big\}.$$





Given exhaustion at T, we know that the price path must be continuous at T, and we can use this to show that

$$p_q(t) = \min \Big\{ \beta(t)(u_c + \phi_c \tau(t)),\; \beta(t) u_r(t),\; \frac{1}{\epsilon - 1} \left(\bar{p}_w^{-\delta/\epsilon} \bar{v}^{-1/\epsilon} + \epsilon u_q \right) \left(1 - e^{-r(T-t)} \right) + \frac{\epsilon}{\epsilon - 1} \phi_q \left(\tau(t) - \tau(T) e^{-r(T-t)} \right) + \beta(T) p_w(T) e^{-r(T-t)} \Big\}.$$

The previous result is a special case (the limit when $T \to \infty$)...

$$p_q(t) = \min \Big\{ \beta(t)(u_c + \phi_c \tau(t)),\; \beta(t) u_r(t),\; \frac{1}{\epsilon - 1} \bar{p}_w^{-\delta/\epsilon} \bar{v}^{-1/\epsilon} + \frac{\epsilon}{\epsilon - 1} (u_q + \phi_q \tau(t)) \Big\}.$$

$U = \int \left[Y - X - \phi A(t) S(t) \right] e^{-rt} \mathrm{d}t$

$\tau^P = \phi A_0 / (r - g) e^{gt} = \psi e^{gt}$

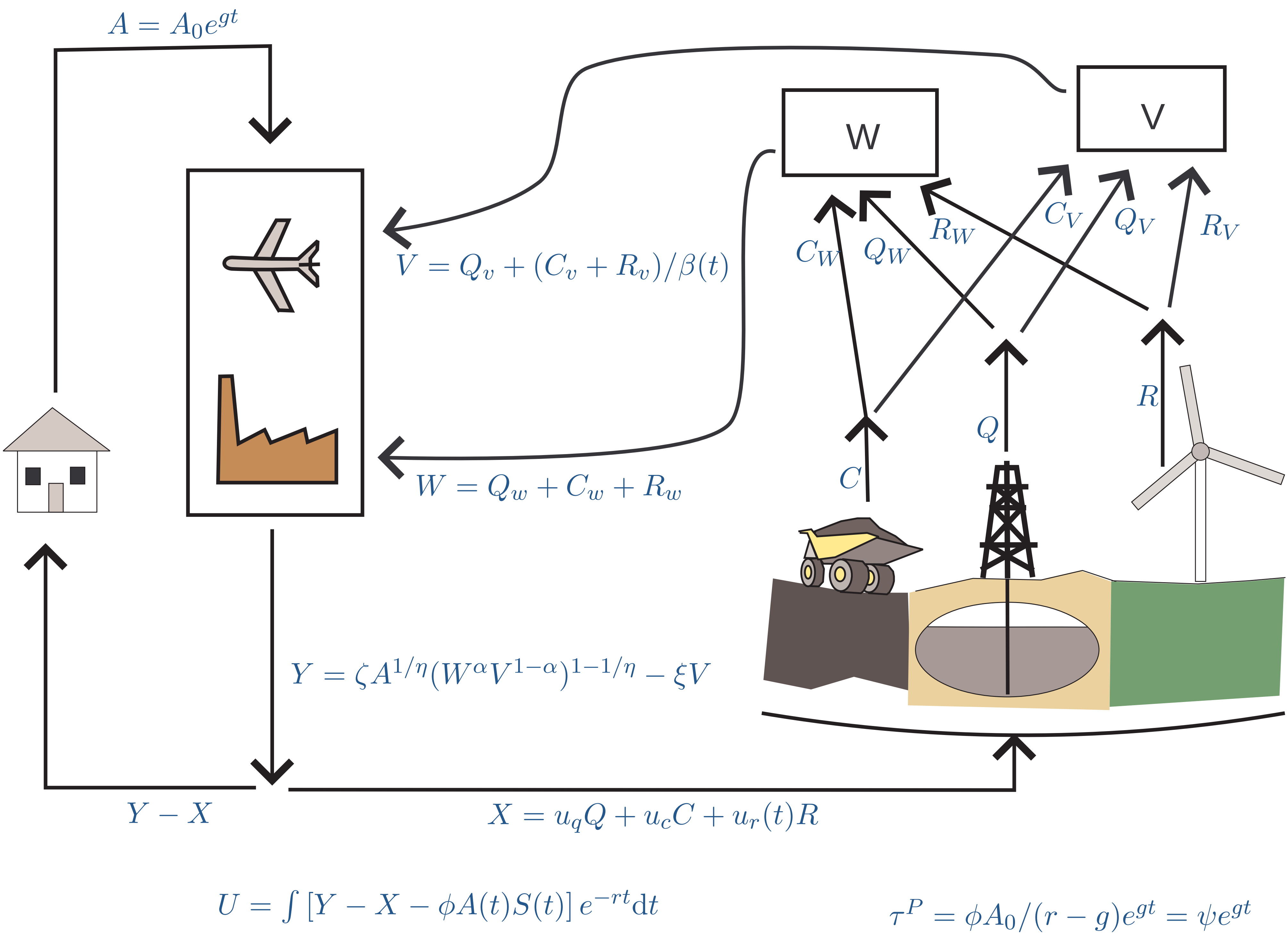
Regulatory options

We now have all the ingredients we need to solve for the development of the economy, except the specification of the regulator's actions.

Three alternatives:

- Laissez-faire;
- Naive Pigou;
- Optimal tax.

Laissez faire



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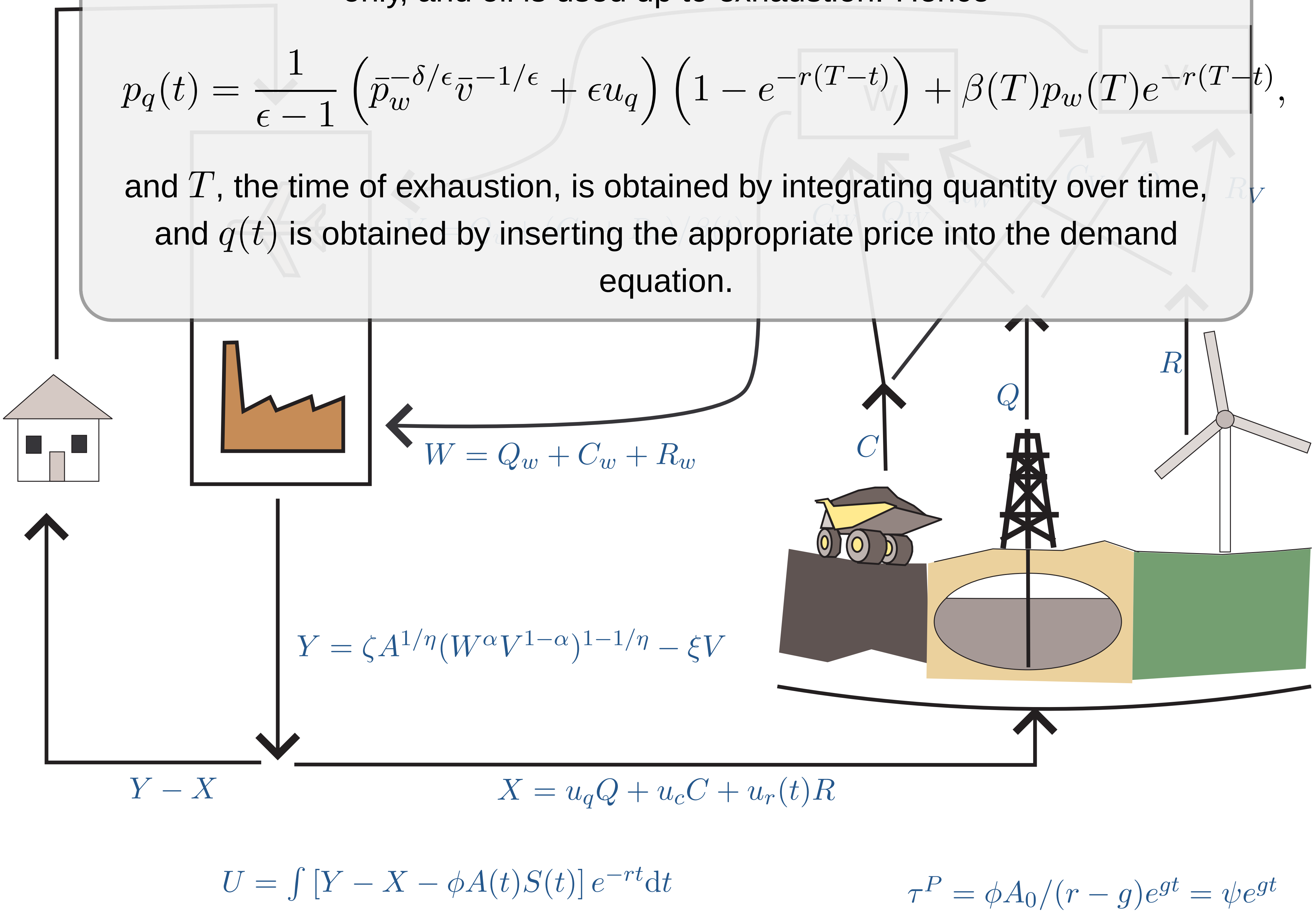
$U = \int [Y - X - \phi A(t)S(t)]\, e^{-rt} \mathrm{d}t$
$\tau^P = \phi A_0/(r-g)e^{gt} = \psi e^{gt}$

We focus on the case in which the monopolist supplies the vehicle market only, and oil is used up to exhaustion. Hence

$$p_q(t) = \frac{1}{\epsilon - 1}\left(\bar{p}_w^{-\delta/\epsilon}\bar{v}^{-1/\epsilon} + \epsilon u_q\right)\left(1 - e^{-r(T-t)}\right) + \beta(T) p_w(T) e^{-r(T-t)},$$

and T, the time of exhaustion, is obtained by integrating quantity over time, and $q(t)$ is obtained by inserting the appropriate price into the demand equation.



Naive application of a Pigovian tax

Naive application of a Pigovian tax

Recall our previous result.

$$p_q(t) = \min\Big\{\beta(t)(u_c + \phi_c\tau(t)), \beta(t)u_r(t), \frac{1}{\epsilon-1}\left(\bar{p}_w^{-\delta/\epsilon}\bar{v}^{-1/\epsilon} + \epsilon u_q\right)\left(1 - e^{-r(T-t)}\right) + \frac{\epsilon}{\epsilon-1}\phi_q\left(\tau(t) - \tau(T)e^{-r(T-t)}\right) + \beta(T)p_w(T)e^{-r(T-t)}\Big\}$$

Set $\tau(t) = A_0\psi e^{gt}$ (let $T \to \infty$ if no exhaustion).

Reasonable parameterizations: oil price at the limit to exclude renewables and coal from the vehicle market (see next section for a simulation). This high oil price—well above first-best—may let coal into the electricity market, as we see in the simulation.

First-best emissions regulation

First-best emissions regulation

Case 1, no exhaustion hence no scarcity rent.

First-best emissions regulation

Denote the time at which oil extraction stops as T^*. Apply a tax (or subsidy!) on oil such that it is offered on the market at the price $u_q + \phi_q \psi e^{gt}$ for all $t < T^*$. (Coal still taxed at Pigou.) To find the appropriate tax path, take the appropriate equation for $p_q(t)$ and substitute $p_q(t)$ by $u_q + \phi_q \psi e^{gt}$, then rearrange to obtain the following equation for $\tau(t)$:

$$\tau(t) = \frac{\epsilon - 1}{\epsilon} \psi e^{gt} - \frac{1}{\epsilon \phi_q} \left(u_q + \bar{p}_w^{-\delta/\epsilon} \bar{v}^{-1/\epsilon} \right). \tag{1}$$

Note also that from T^* onwards the oil tax should jump to the Pigovian level (and not be set at the level given by the above equation), otherwise the monopolist will continue supplying oil at the limit price, excluding renewables and making a gradually dwindling surplus.

First-best emissions regulation

Recall that we denote the Pigovian tax $\tau^p(t)$. So $\tau^p(t) = \psi e^{gt}$, and

$$\frac{\tau^p(t) - \tau(t)}{\tau^p(t)} = \frac{1}{\epsilon} + \frac{1}{\epsilon\psi\phi_q}\left(u_q + \bar{p}_w^{-\delta/\epsilon}\bar{v}^{-1/\epsilon}\right)e^{-gt}. \quad (1)$$

So, by inspection, the first-best tax on oil is always less than the Pigovian tax, but as t increases from 0 to T^*, the percentage gap between the Pigovian tax and $\tau(t)$ decreases monotonically. However, note that the rate of increase of the tax (note, not the growth rate) $\dot{\tau} = [(\epsilon - 1)/\epsilon]g\psi e^{gt}$, which is less than the rate of increase of the Pigovian tax, $\dot{\tau}^p = g\psi e^{gt}$.

First-best emissions regulation

Case 2, exhaustion.

First-best emissions regulation

We choose the tax path which leads to zero scarcity rent, implying that the tax per unit of oil payable by the oil producer at the time of exhaustion is equal to the current value of the planner's scarcity rent at that time, $\phi_q \tau(T) = \mu^* e^{rT}$.
Then

$$\tau(t) = \frac{\mu^* e^{rT}}{\phi_q} - \frac{\epsilon - 1}{\epsilon} \psi (e^{gT} - e^{gt}).$$

Note that the rate of increase of this tax is, as above, $[(\epsilon - 1)/\epsilon] g \psi e^{gt}$, which is (again) less than the rate of increase of the Pigovian tax.

Conclusions

An oil monopoly may increase total carbon emissions under naive (Pigovian) regulation by encouraging the use of coal which would (in first best) remain in the ground.

In our very simple set-up with a single economy and a focus on the optimal allocation of productive resources (and no attention paid to the distribution of income), the policy implication is that if a Pigovian tax is applied, there should also be a subsidy to oil consumption, which gradually declines over time as the market power of the oil monopolist weakens.

In a more realistic setting with multiple countries and distributional concerns, subsidizing oil consumption is unlikely to be an acceptable (or optimal) policy option.

Under these circumstances the simplest strategy might be to simply ban the use of coal, or (in a multicountry setting) buy foreign coal deposits (cf. Harstad 2012 and others).

The benchmark model is very highly stylized, and a key drawback is that we assume a single homogeneous oil stock, and an oil monopolist.

Next paper: model an oil cartel with a large homogeneous stock, and a series of competitors with smaller stocks which were also more expensive to extract: oligopoly in the oil market, or (to quote Loury, 1986), oiligopoly.

As here, market power applied by the cartel leads to extraction from more expensive sources (even under naive Pigou), stocks that would be left in ground in first best.